BULLETIN

OF THE INSTITUTE OF METALS

VOLUME 2 DECEMBER 1953 PART 4

INSTITUTE NEWS

Elections to the Council

The following members have been declared elected to the Council, to take office at the 1954 Annual General Meeting:

As President:

S. F. DOREY, C.B.E., D.Sc., F.R.S., M.I.C.E., M.I.Mech.E., Chief Engineer Surveyor, Lloyd's Register of Shipping, London.

As Vice-Presidents:

MAURICE COOK, D.Sc., Ph.D., F.I.M., Joint Managing Director, Imperial Chemical Industries, Ltd., Metals Division, Birmingham.

L. B. PFEIL, O.B.E., D.Sc., A.R.S.M., F.R.S., F.I.M., Director, The Mond Nickel Co., Ltd., and Henry Wiggin and Co., Ltd., London.

Major P. LITHERLAND TEED, A.R.S.M., F.R.Ae.S., M.I.M.M., F.I.M., Assistant Chief of Aeronautical Research and Development, Vickers-Armstrongs, Ltd. (Aircraft Section), Weybridge.

As Ordinary Members of Council:

R. D. HAMER, B.Sc., Dipl.Ing., F.I.M., Vice-President and Director, Aluminium Laboratories, Ltd., Banbury, and Director, Magnesium Company of Canada, Ltd., Montreal.

G. P. TINKER, M.Sc., F.I.M., Managing Director, Birlec, Ltd., and Director, Birmingham Electric Furnaces, Ltd., Birmingham.

Informal Discussion on Lubricants for Metal-Working Operations in the Non-Ferrous Metals Industry

An Informal Discussion, organized by the Metallurgical Engineering Committee, and under the chairmanship of Mr. W. J. THOMAS, M.I.Mech.E., will be held at The University, Edgbaston, Birmingham 15, on Wednesday, 6 January 1954, on "Lubricants for Metal-Working Operations in the Non-Ferrous Metals Industry". The meeting will begin at 10.30 a.m. and end at 4.30 p.m. Lunch may be obtained in the University Refectory (price 4*s.* 6*d.*) if ordered by members and guests from the Secretary of the Institute not later than 31 December.

The discussion, which will *not* cover lubrication in machining operations or the lubrication of machinery, bearings, &c., will be organized as follows:

Morning Session

(1) Introductory Address.
(2) Lubricants for the Hot Working of Light Metals.
(3) Lubricants for the Hot Working of Other Non-Ferrous Metals and Alloys.

Afternoon Session

(4) Lubricants for the Cold Rolling of Non-Ferrous Metals and Alloys.
(5) Lubricants for the Cold Drawing of Non-Ferrous Metals and Alloys.

Speakers in the discussion will be limited to a maximum of 10 minutes.

Visitors will be welcome. Tickets of admission are not required.

1954 Annual Dinner: Change of Date

The annual Dinner and Dance will be held in the Great Room, Grosvenor House, London, W.1, on Wednesday, 28 April 1954, and *not* on Thursday, 29 April, as stated in the printed pocket programme of meetings, which members are requested to amend accordingly. The change has been made necessary to avoid clashing with another, similar function.

On this occasion, members and ladies of the Société Française de Métallurgie will be the guests of the Institute at a joint Spring Meeting, which members of the Iron and Steel Institute are also invited to attend on the same basis as members of the Institute of Metals.

In the Great Room at Grosvenor House, 1000 people can dine and dance in comfort. It is hoped, therefore, that members will support this function by bringing parties of friends and attending in large numbers.

Honorary Corresponding Members to the Council

The Council has accepted, with regret, the resignation of Professor B. CHALMERS as an Honorary Corresponding Member for Canada, which he tendered on taking up an appointment in the United States.

Professor F. A. FORWARD, Head of the Department of Mining and Metallurgy in the University of British Columbia has been appointed an Honorary Corresponding Member to the Council for Canada.

Dr. O. H. C. MESSNER, Metallurgical Consultant, of Zürich, has been appointed an Honorary Corresponding Member to the Council for Switzerland.

1954 May Lecture

Professor L. F. BATES, Ph.D., D.Sc., F.R.S., Head of the Department of Physics at the University of Nottingham, has accepted the Council's invitation to deliver the 1954 May Lecture in the Lecture Theatre of The Royal Institution on the evening of Monday, 26 April. His lecture will deal with magnetic characteristics of metals.

Metal Physics Committee's Informal Discussion

The Metal Physics Committee is organizing an Informal Discussion on "Recovery and Recrystallization", to be held in London on the morning of Thursday, 29 April 1954, in connection with the Joint Spring Meeting with the Société Française de Métallurgie.

1954 Autumn Lecture

Professor A. VON ZEERLEDER has accepted the Council's invitation to deliver the 1954 Autumn Lecture in Zürich on "Attempts to Improve Aluminium Reduction Since Hérault and Hall".

Powder Metallurgy Symposium

The Council has accepted an invitation from the Council of the Iron and Steel Institute for the Institute of Metals to be associated with the organization of a Symposium on powder metallurgy, to be held in 1954, and has appointed Dr. L. B. PFEIL, O.B.E., F.R.S., to be the Institute's representative on the Organizing Committee.

Students' Educational Tours

There will be no Students' Educational Tour in 1954. Enquiries are being undertaken to ascertain the probable future demand for these tours in subsequent years.

Monograph on "The Control of Quality in Melting and Casting"

The six papers contributed to the Symposium held last March on "The Control of Quality in the Production of Wrought Non-Ferrous Metals and Alloys. I.—The Control of Quality in Melting and Casting", have now been reprinted, together with an abridged account of the discussion, as No. 15 in the Institute's Monograph and Report Series. The published price is 15*s.* ($2.50), post free, but each member may obtain one copy at the privileged price of 7*s.* 6*d.* ($1.50), post free.

Binding of the Journal, Bulletin, and Metallurgical Abstracts

It is recommended that members resident in the United Kingdom should arrange for the binding of their annual volumes to be undertaken by Mr. W. A. Newark, 2 Clerkenwell Green, London, E.C.1, whose charges are as follows: *Journal* and *Metallurgical Abstracts* 10*s.* 3*d.* per volume and *Bulletin* 9*s.* 6*d.*, inclusive of postage to members' addresses.

Members who desire to bind their volumes in the official binding cases should register with the Institute to be provided with these, free of cost, as received from the printer. Those who decide to employ Mr. Newark to bind their volumes are requested to notify the Secretary of this fact, so that their binding cases may be sent direct to Mr. Newark, to obviate damage and duplicate postage.

Annotated Equilibrium Diagram: Copper–Silver System

No. 10 in the series of Annotated Equilibrium Diagrams published by the Institute is now available. It covers the copper–silver system and has been prepared by Dr. J. C. Chaston. Copies may be ordered at the following rates:

Members (one copy only at) .	1*s.* 0*d.* or $0.40
Non-members . . .	2*s.* 0*d.* or $0.50
Libraries	1*s.* 8*d.* or $0.40

Elections of Members

The following 29 Ordinary Members, 2 Junior Members, and 2 Student Members were elected on 19 October 1953:

As Ordinary Members

ANTHONY, Harry L., III., Sc.D., Mellon Institute of Industrial Research, 4400 Fifth Avenue, Pittsburgh 13, Pa., U.S.A.

BERTOSSA, Robert C., B.S., Plant Metallurgist, Chicago Bridge and Iron Company, P.O. Box 227, Birmingham, Ala., U.S.A.

BRATINA, Woymir John, Dipl.Ing., M.A.Sc., Research Assistant, Department of Metallurgy, University of Toronto, Ont., Canada.

CAUNCE, Eric M. P., Chief Chemist and Metallurgist, Ford Motor Company of Canada, Ltd., Windsor, Ont., Canada.

CHARLIER, *Professor* Emile Henri Gabriel, Ing.Tech., Professor of Metallurgy, Institut Gramme de Liège, 1 quai du Condroz, Angleur-Liège, Belgium.

COUCH, John Morgan, Assistant Metallurgist, Metallurgical Department, Guest Keen Baldwins Iron and Steel Co., Ltd., East Moors, Cardiff.

DEUTSCH, Raymond, President, Monarch Aluminum Manufacturing Company, 9205 Detroit Avenue, Cleveland 2, Ohio, U.S.A.

DISTURNAL, Leonard Ernest, Manager, Metals Division, Harrison (Birmingham), Ltd., Bradford Street, Birmingham 12.

DRUMMOND, Arthur Clarence, Secretary and General Manager, Lead Industries Development Council, Eagle House, Jermyn Street, London, S.W.1.

FLORANCE, John R., Works Metallurgist, Evered and Co., Ltd., Surrey Works, Smethwick, Staffs.

FORBES, Norman, A.C.I.S., Director and Secretary, The Wednesbury Tube Co., Ltd., Bilston, Staffs.

HOOKANSON, Kenneth G., B.S., Chief Metallurgist, The H.M. Harper Company, 8200 North Lehigh Avenue, Morton Grove, Ill., U.S.A.

IVANSO, Eugene V., M.S., Vice-President, The Detroit Testing Laboratory, Inc., 554 Bagley Avenue, Detroit 26, Mich., U.S.A.

JOHANSSON, Axel, Chief Engineer, Research Laboratory, STAL, Finspong, Sweden.

KAMEN, Elliott Leroy, B.Met.E., M.S., Department K-90, Westinghouse Electric Corporation, Materials Division, East Pittsburgh, Pa., U.S.A.

KLAYER, Walter J., Director of Research and Chief Metallurgist, Aluminum Industries, Inc., Werk Road Plant, Cincinnati 11, O., U.S.A.

KLOHR, George W., B.S., Technical Specialist, Technical Section, E.I. du Pont de Nemours and Company, P.O. Box 993, Charleston 24, W. Va., U.S.A.

LI, Choh-Hsien, M.S., Junior Research Engineer, Institute of Engineering Research, University of California, Berkeley 4, Calif., U.S.A.

MUNDAY, John Worthington, B.Eng., F.I.M., Chief Metallurgist, High Duty Alloys, Ltd., Forging Division, Windsor Road, Redditch, Worcs.

PARLANTI, Conrad Anthony, F.I.M., Technical Director, Carron Parlanti, Ltd., Carron, Falkirk, Stirlingshire.

POGGIO, José A., Aeronautical Engineer, Laboratorio Metalûrgico del Instituto Nacional de Tecnica Aeronautica, Madrid, Spain.

RANKINE, John, B.Sc., M.I.Mech.E., Manager, General Engineering Department, Northern Aluminium Co., Ltd., Rogerstone, Newport, Mon.

STAPLES, John A., M.E., Superintendent, Tube Mill, Lewin Mathes Company, Twelfth and Chouteau, St. Louis, Mo., U.S.A.

STRADAR, George Francis, Chem.E., Chief Metallurgist, Fairchild Camera and Instrument Corporation, Robbins Lane and Landis Drive, Syosset, L.I., N.Y., U.S.A.

TAYLOR, Harry, Chief Metallurgist, Banbury Works, Northern Aluminium Co., Ltd., Banbury, Oxon.

TURNER, Wilfred, Chemist, Research Laboratory, Allen West and Co., Ltd., Lewes Road, Brighton, Sussex.

VOSPER, Robert Gordon, M.A., Director of Libraries, University of Kansas Library, Lawrence, Kans., U.S.A.

WESTWOOD, Arthur, B.Sc., A.I.M., Metallurgist, Imperial Chemical Industries, Ltd., Metals Division, Kirkby, Liverpool.

WILD, Norman, A.M.C.T., L.I.M., Metallurgist, Lloyds (Burton), Ltd., Wellington Street, Burton-on-Trent, Staffs.

As Junior Members

HAINS, Robert Warren, B.Sc., Assistant Metallurgist, Northern Aluminium Co., Ltd., Rogerstone, Newport, Mon.

PRIOR, Trevor Vincent, B.A., Assistant Technical Officer, Research Department, Imperial Chemical Industries, Ltd., Metals Division, Kynoch Works, Witton, Birmingham 6.

As Student Members

GREENHILL, John Malcolm, Foundry Metallurgist, Sterling Metals, Ltd., Coventry.

KRETLOW, Robert Lawrence, B.S., Graduate Student, Illinois Institute of Technology, Technology Centre, Chicago 16, Ill., U.S.A.

The following 17 Ordinary Members and 19 Student Members were elected on 9 November 1953 :

As Ordinary Members

ABBOTT, R. D., B.Sc., Metallurgist, Strength of Materials Department, Research Laboratories, The General Electric Co., Ltd., North Wembley, Middlesex.

BARRETT, Arthur Stephen Dennis, B.Sc., M.I.Mech.E., A.M.I.Chem.E., Technical Director, W. Edwards and Company (London), Ltd., Manor Royal, Crawley, Sussex.

BRECKON, Clifford, B.Sc., A.R.I.C., A.I.M., Deputy Chief Metallurgist, The Yorkshire Copper Works, Ltd., Leeds.

COOK, Andrew McTurk, Chairman and Managing Director, William Cook and Sons (Sheffield), Ltd., Washford Road, Sheffield 9.

CROSS, Frederick Alexander, Representative Agent, N. C. Ashton, Ltd., St. Andrews Road, Huddersfield, Yorks.

ELLINGER, Finley Harrison, B.S., Met.E., Metallurgist, Los Alamos Scientific Laboratory, Los Alamos, N. Mex., U.S.A.

EVANS, Arthur Fannin, B.Sc., A.I.M.M., Manager, The Electrolytic Refining and Smelting Company of Australia, Pty., Ltd., P.O. Box 42, Port Kembla, N.S.W., Australia.

FARMER, M. H., B.Sc., Research Metallurgist, Metallurgy Division, National Physical Laboratory, Teddington, Middlesex.

FLUBACHER, Franz, Dipl.Ing., Foundry Manager and Metallurgist, Britannia Iron and Steelworks, Ltd., 1 Kempston Road, Bedford.

GOULD, James C., B.Ch.E., Research Metallurgist, Federal Mogul Corp., Research and Development, 2355 West Stadium Boulevard, Ann Arbor 1, Mich., U.S.A.

MACK, David Josef, M.S., Ph.D., Associate Professor of Metallurgical Engineering, College of Engineering, University of Wisconsin, Madison 6, Wis., U.S.A.

REEN, Orville Wallace, B.Met.E., M.S., Research Metallurgist, Allegheny Ludlum Steel Corp., Carmet Division, 1500 Jarvis Avenue, Detroit 20, Mich., U.S.A.

RUSTAY, Arnold Luther, Director of Research, Wyman-Gordon Company, 105 Madison Street, Worcester 1, Mass., U.S.A.

VESTEY, George, Works Manager, British Lead Mills, Ltd., Peartree Lane, Welwyn Garden City, Herts.

WAGNER, Nicholas Alfon, Chief Plant Metallurgist, Reynolds Metals Company, Beverly and Porter Streets, Grand Rapids 9, Mich., U.S.A.

WOOLLEY, Robert Lewis, M.A., Ph.D., A.Inst.P., Lecturer in Physics, Natural Philosophy Department, University of St. Andrews, St. Andrews, Fife.

YOUNG, Peter Alexander, M.A., Metallurgist, Ernest Oppenheimer Laboratory, Departments of Colloid Science and Metallurgy, University of Cambridge, Madingley Road, Cambridge.

As Student Members

BIRNIE, John Victor, Student, Department of Metallurgy, University of Manchester.

CHITTY, Anthony, B.Sc., Postgraduate Student of Metallurgy, Royal School of Mines, London, S.W.7.

COLLEY, David Edwin, Student, Department of Metallurgy, University of Manchester.

COX, Gordon John, Assistant Metallurgist, The Rollason Wire Co., Ltd., Bromford Lane, Birmingham 24.

ELEY, William George James, Student of Metallurgy, Battersea Polytechnic, London, S.W.11.

GJOSTEIN, Norman Arthur, B.S., Graduate Student, Illinois Institute of Technology, Technology Centre, Chicago 16, Ill., U.S.A.

HILL, Keith, Student, Department of Metallurgy, University College, Swansea, Glam.

HUGHES, Albert Norman, Student, Department of Metallurgy, University of Manchester.

JAMES, David Benjamin, Student, Department of Metallurgy, University College, Swansea, Glam.

JOHNSON, William Kenneth, Student, Department of Metallurgy, University of Manchester.

LEE, John, Metallurgical Chemist, Alfred Herbert, Ltd., Edgwick Works, Foleshill, Coventry.

MADHEKAR, Mukund Keshar, B.E., Student of Metallurgy, College of Technology, Manchester.

MORGAN, Hywel Lynne, Metallurgist (on National Service), 138 Cwmamman Road, Glanamman, near Ammanford, Carmarthenshire.

PETTY, Evan Robert, Student, Department of Metallurgy, University College, Swansea, Glam.

POLONIS, Douglas Hugh, M.A.Sc., Graduate Research Student, Department of Mining and Metallurgy, University of British Columbia, Vancouver 8, B.C., Canada.

SHELMERDINE, Aubrey Brian, Student, Department of Metallurgy, University of Manchester.

STRINGER, John, Student, Department of Metallurgy, University of Liverpool.

SZAJDA, Thaddaeus Jaroslaus, Student, Department of Metallurgy, University College, Swansea, Glam.

WALLWORK, Alfred, Apprentice Metallurgist, Stewarts and Lloyds, Ltd., Bilston, Staffs.

PERSONAL NOTES

PROFESSOR P. G. BASTIEN delivered the opening lecture at the International Foundry Congress held in Paris in September.

MR. S. C. BOYLE has been appointed Manager of Modern Electrolytic Patents and Processes, Ltd., Saltisford, Warwick, and also Works Metallurgist to Warwick Production Co., Ltd.

DR. A. B. EVEREST, of The Mond Nickel Co., Ltd., was awarded the Gold Medal of the Association Technique de Fonderie at the International Foundry Congress held in Paris in September.

MR. F. E. HAYES is now at the Royal Ordnance Factory, Bambow, Leeds.

MR. C. C. HORNE has left the Royal Technical College, Glasgow, to take up an appointment with Henry Wiggin and Co., Ltd., Thornliebank.

PROFESSOR W. R. D. JONES, Head of the Metallurgy Department at University College, Cardiff, has been elected President of the South Wales Institute of Engineers.

MR. A. J. KNOWLES has been appointed Chief Chemist to John Allan and Co. (Glenpark), Ltd., Oldbury, Birmingham.

DR. T. KO has left Birmingham University and gone to the Institute of Metallurgical Research, Academia Sinica, Shenyang, China.

PROFESSOR A. J. MURPHY, has been appointed Director of the Combined Departments of Metallurgy in the University of Birmingham in succession to the late Professor D. Hanson.

MR. J. F. PAIGE has been appointed representative of L.M.F.A. Development, Ltd., on the Council of the Aluminium Development Association.

DR. N. H. POLAKOWSKI has left University College, Swansea, to join The Armzen Company, Waterbury, Conn., U.S.A. His business address is at present: Sendzimir Ltd., 75 Grosvenor Street, London, W.1.

MR. T. D. REES has transferred from the Milton Works to the Warrington Works of The British Aluminium Co., Ltd.

DR. J. SAWKILL has left Sheffield University and is now at the P.C.S. Laboratory, Department of Physical Chemistry, Free School Lane, Cambridge.

MR. J. A. TOD has transferred from Broughton Copper Works, Manchester, to the new works of Imperial Chemical Industries, Ltd., Metals Division, at Kirkby, Liverpool.

MR. J. M. WEST has left Cambridge University and is now with Imperial Chemical Industries, Ltd., Billingham Division.

MR. H. WILKINSON is now Metallurgical Engineer with the Canadian General Electricity Company, Ltd., Quebec City, Canada.

MR. W. WILSON has taken up an appointment with The Welwyn Foundry Co., Ltd., Welwyn Garden City, Herts.

DR. B. C. WOODFINE has left Sheffield University and joined the British Iron and Steel Research Association.

MR. A. J. ZULLIG has been appointed Managing Director of the Aluminium Company of South Africa (Pty.), Ltd., Pietermaritzburg, Natal.

Death

The Editor regrets to announce the death of

PROFESSOR EUGEN PIWOWARSKY, Director of the Giesserei-Institut at the Technische Hochschule, Aachen, on 17 October 1953.

OBITUARY

O. F. Hudson

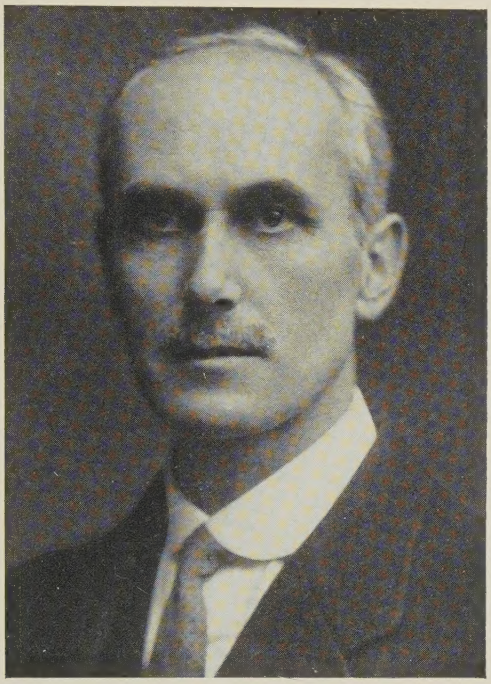
The death of Dr. O. F. Hudson, which occurred on 8 October 1953, will be regretted by a wide circle of friends, many of whom owed much to his teaching and guidance in the technique and practice of metallography, in which he attained eminence at a time, in the early years of this century, when there were but few workers in that field. He will be missed, too, by a number of those who, as colleagues, were associated with him in later years.

Born in 1878, Oswald Freeman Hudson was educated at Alleyn's School, Dulwich. From there he matriculated at the University of London in 1895 and entered the Royal College of Science in 1897, gaining the Associateship in Chemistry in 1900. He remained on for another year at South Kensington to take the course in metallurgy at the Royal School of Mines. He was then invited by his Professor (Roberts-Austen) to go to the Mint as one of his private assistants in the research laboratory, where, over a long period of years, so much work had been done for the Alloys Research Committee, sponsored by the Institution of Mechanical Engineers. Work was then in progress for the Sixth Report, and it was here that Hudson had what, at that time, was an almost unique opportunity; that of acquiring, under the late W. H. Merrett, the rapidly developing technique of metallography, the future importance of which Roberts-Austen had foreseen and was tirelessly advocating when doubts still lingered as to its utility.

It was not long, however, before Hudson was invited by the late Professor Turner to join him, as his Lecturer in Metallography, at the newly established University of Birmingham, where the School of Metallurgy which Turner had been steadily building up at Mason's College became the nucleus of the Department which has since achieved such

eminence. Hudson remained at Birmingham from 1902 until 1916, and the sincere regard in which he was held by Turner was expressed to the writer on many occasions. Many former students there will cherish grateful recollections of Hudson's help and friendship.

During the First World War, however, in 1916, Hudson's services were enlisted by the Corrosion Research Committee, which, under the auspices of the Institute of Metals and the Chairmanship of the late Sir Harold Carpenter, had for some years been engaged in what was virtually a nationally sponsored series of investigations, arising as they did, in the first instance, from the serious troubles experienced by the Royal Navy in regard to water-tube boilers. From 1916 to 1918 Bengough and Hudson collaborated in this work (later to be joined by



Ralph May) at the Royal School of Mines, and their names are jointly associated with the Fourth Report of that Committee.

In 1918, Hudson was appointed to the newly created post of Metallurgist at the Admiralty Engineering Laboratory at West Drayton, where he remained until 1924.

At that time Dr. R. S. Hutton was engaged in setting up the British Non-Ferrous Metals Research Association, and he invited Hudson to join him as Research Superintendent. He continued in this post for the next 15 years, after which he was retained as Consultant (part time) for a further 5 years.

This long and exacting period of work covering more than 40 years, during which Hudson had taken a prominent part in what were, in fact, a series of pioneering undertakings, had already taxed a constitution which had never been robust. Nevertheless, when the Second World War, resulting in the calling away of many key-men from the teaching profession, left gaps which were difficult to fill, Hudson nobly responded to calls for assistance in lecturing and instruction in metallography. This he gave at Cambridge (1940–43) and at the Royal School of Mines (1942–45).

Of his many contributions to the progress of physical metallurgy, both as regards metallography and also the corrosion of metals, much might be said. It was during his 14 years at Birmingham that much of his patient and meticulously careful pioneering work in regard to non-ferrous alloys was done, although the publication of a text-book for engineers and metallurgists on "Iron and Steel" in 1913, in collaboration with Dr. G. D. Bengough, shows the breadth of his metallurgical interests. In the years preceding the foundation of the Institute of Metals (in 1908) the results of his researches had been appearing in the *Journal of the Society of Chemical Industry*, the only medium, at that time, which afforded opportunities for the publication of such work. In this connection, particular mention should be made of a paper on "The Microstructure of Brass" (1906) and of two papers, in collaboration with Bengough, on "Muntz Metal": Parts I and II, under the general title of "The Heat-Treatment of the Copper–Zinc Alloys". These papers, like the classic work of Shepherd, have in some measure lacked full recognition from having pre-dated the foundation of the Institute. With the advent of that body, however, of which Hudson was an Original Member, he became a regular contributor, both to its *Journal* and to the discussions. In 1921 he took a leading part in the formation of the London Local Section and became its first Chairman.

In the earlier volumes of the *Journal* will be found numerous papers under Hudson's name, sometimes alone and sometimes in collaboration with Bengough and others; most of them dealt with the heat-treatment and metallography of copper and its alloys. His later work was, of course, carried out in collaboration with his colleagues of the British Non-Ferrous Metals Research Association. An important paper on "The Properties of Locomotive Firebox Stays and Plates" (1929) covered much work on the effects of small quantities of added elements on copper. This was followed by papers on the "Properties of Copper in Relation to Low Stresses" (1932) and the "Stress–Strain Characteristics of Copper, Silver, and Gold" (1937), both in collaboration with Dr. J. McKeown.

As one of the pioneers in the application of metallographic methods to a better understanding of the behaviour of non-ferrous metals and alloys under thermal treatment, Hudson has left a record of which anyone might be proud. One who knew him well and who was one of his earliest students at Birmingham, has recently expressed to the writer the high regard he had always had for him and the feeling that his pioneer work both in metallography and in regard to the problems of corrosion, have received less recognition than might have been accorded to a less self-effacing and modest personality.

S. W. Smith.

William Singleton

Mr. William Singleton, who died suddenly on 11 September, was Joint Managing Director of British Lead Mills, Ltd., and a Member of the Management Committee of the Lead Sheet and Pipe Manufacturers' Federation. He had been connected with the lead trade since 1930, and was a recognized authority on all matters appertaining to lead, and a joint patentee of tellurium–lead alloy.

His kindly nature and his natural ability to recognize the other man's problems were greatly appreciated by all with whom he came in contact, both in and out of business, and his loss will be felt by a very large circle of friends and acquaintances.

Mr. Singleton had been a member of the Institute since 1932 and regularly attended its General Meetings.

Local Section Symposium

B5 MAKING THE BEST OF METALS*

NON-FERROUS METAL RESOURCES

By R. LEWIS STUBBS,† O.B.E.

SINCE I last spoke [1] about non-ferrous metal resources at the Institute of Metals meeting in London in October 1951 the situation appears to have changed very much; most shortages have now vanished, and nearly all metals are readily available everywhere. The fears that the world's resources might soon be exhausted have also subsided, the monumental report of the U.S. President's Materials Policy Commission [2] (generally known as the Paley Commission) having dispelled any doubts which remained. However, I do not think that the fundamental reasons for our fears have altered at all: the world mineral resources are limited, but the demand is still growing, and more and more metal will be needed as industrial production rises.

Britain, which is the second largest consumer of metals, occupies a unique and perhaps somewhat precarious position today, since it is the only very large manufacturing country with practically no non-ferrous mineral resources of its own, and so may be more affected than others by changes which the growing demand for metals may bring about. Therefore in reviewing the latest estimates for world resources I am going to discuss their distribution; and I shall also examine the changes which have occurred since the war in consumption and production and consider where production is most likely to be expanded. I shall cover all the main non-ferrous metals, i.e. copper, zinc, lead, aluminium, magnesium, nickel, and tin.

The World's Resources of Non-Ferrous Metals

Non-ferrous metal resources fall into two categories. First, and most important, are minerals which, once used up, cannot be replaced; and second, metal contained in old scrap, which increases in volume as new metal is fabricated and more metal goods come into use.

Mineral Resources

Our recent shortages led many people to believe that mineral resources were being rapidly depleted and that some metals would always be scarce in future. It is true that if we continue to consume metals at ever-increasing rates a time may come when we shall suffer real shortages, particularly of those metals which have been used longest, but that day is still a long way ahead. Methods of extraction are constantly improving, and no doubt our present pattern of consumption will prove as different from that fifty years hence as it is from that of fifty years ago. It would be foolish to practise economies or to seek substitutes now simply on the grounds that one day in the distant future a metal might become scarce.

The latest estimates of mineral resources are those made by the Paley Commission; as usual when new estimates are published, they exceed those previously made. In addition, the recent period of shortages and high prices has stimulated prospecting and there have been reports of many important new ore bodies being discovered in the past year or so.

Let us compare the Paley Commission's figures with some previous estimates. No figures are given for magnesium, as the main raw material in future is likely to be sea-water.

TABLE I.—*World's Metal Reserves*

(Metal content thousands of metric tons)

Metal	Rate of Consumption, 1950	Estimated World Reserves			
		Paley Commission, 1952	Previous Estimates	Year	Ref.
Aluminium	1300	1,800,000	...	...	...
Copper	2200	216,000	100,000 90,000	1947 1935	3 4
Zinc	2000	80,000	70,000 63,000 43,000 21,000	1948 1947 1940 1931	6 7 8 9
Lead	1800	45,000	36,000 31,000 32,500	1952 1948 1947	5 6 7
Tin	170	6,600	...	...	...
Nickel	120	...	6,000	1950	10

These estimates are made up in different ways and include some proved reserves, some indicated, and others which have only been inferred. No doubt they tend to be conservative, and are therefore no indication of the total amounts which might eventually be available. Most, at the time they were made, represented at least 40 years' consumption at the current rate.

Not more than two-thirds of the surface of the earth can be said to have been explored for minerals and nearly all the great discoveries of the past twenty or thirty years have been made in the so-called explored regions. Most mineral deposits being worked now were discovered without the aids of modern equipment and many of the European deposits were known in Roman times. New methods of prospecting, mining, and smelting are constantly being developed, and will contribute

* Papers forming the basis of a Symposium organized by the Birmingham Local Section of the Institute of Metals, and held in Birmingham on 27 February 1953.

† The British Non-Ferrous Smelters Association, Oxford.

to increasing our supplies; as means of locating hidden ore bodies are devised and economic methods of working lower-grade ores are developed, greater supplies of all metals will become available.

Whether a particular ore body can be worked economically depends not only on the nature of the ore, but also on its nearness to industrial centres, the availability of power and transport, the amount of precious metal it contains, and the assurance of a steady market. All these factors account for the differences in the grades of ores which are being worked for each metal in various parts of the world. For example, though some ores contain 6% of copper, others are worked with a copper content below 1%. Another very important factor—perhaps the most important of all—is the price at which the metal can be sold, and I shall discuss this later.

Scrap Resources

When talking of scrap as a resource which can supplement mineral reserves, it is necessary to distinguish between old and process scrap. In practice this is not always easy, and figures for scrap must be used with caution. The supply of old scrap depends first of all on the extent to which a metal was used in the past; in Britain and most European countries, and also in the United States, scrap is an important secondary source of supply, whereas in Canada, Australia, and other new countries whose industrial development has occurred more recently, there is less old metal to draw upon. The supply also depends on the extent to which the uses of a metal allow it to be recovered and on the time lag between initial use and salvage. As more and more new metal is used, the quantity that can be recovered grows and forms a vast reserve to be drawn upon later.

Lead, which is more or less indestructible, has been an important industrial metal since Roman times, and so the amount available for salvage is greater than for other metals. It is easily identified, and today about 40% of the lead we use is derived from scrap. Some 65% of current consumption is in metallic form, and so theoretically recoverable as scrap, the rest being used for pigments, in petrol, and in other ways from which recovery is impossible. With some uses, such as in batteries, the cycle of return is rather short.

The potential reserves of scrap copper, which is also easy to identify, are large, although the return cycle is perhaps longer than for lead. Its main dissipating use is in copper sulphate for agricultural sprays. In many forms, such as brass, bronze, and electrical wire, it can be re-used without metallurgical treatment. About 35–40% of the copper used comes from scrap, of which a half to two-thirds is from salvage. With zinc, scrap is less important, and more difficult to identify, and represents only about 15–20% of the metal consumed. There is little prospect of this proportion being increased, since some of the main uses, such as galvanizing and pigment manufacture, involve the ultimate loss of the metal, and, moreover, the use of brass seems to be declining.

Although tin is used mainly in metallic form, its chief application is as a very thin protective coating on steel, and much of this metal cannot be recovered. Even so, about 30% of the tin used is secondary metal, either salvaged metal or process scrap, recovery methods having been highly developed because of the metal's high price. With nickel, too, which is employed mainly either in plating or as a small alloying addition in other metals, recovery is difficult; in alloy form it is often re-used without actually being separately recovered. The recent development of high-nickel alloys, such as are used in jet engines, and the use of nickel in special steels for guns and armour plate, might lead to larger amounts being available for recovery as scrap.

The total amount of old aluminium scrap, which can also be easily recognized, is smaller, since aluminium has been used on a large scale for a much shorter time than the heavy non-ferrous metals. However, scrap already plays an important part in the aluminium industry, and probably not more than about 20% of the metal is used in a non-recoverable form. Its cycle of return to the pool, which is expanding rapidly, will perhaps be about the same as for lead.

In general, the flow of scrap is affected by trends in consumption and in price, and for this reason it is difficult to assess its real contribution. When consumption rises quickly the flow of scrap naturally cannot keep pace, and if prices are increasing too, this state of affairs is aggravated by a tendency for it to be hoarded. However, the total amount of scrap becoming available each year must grow as more metal is used. Between 1940 and 1950 twice as much aluminium was consumed as in the previous fifty years. In the same ten years half as much copper was used as in the preceding fifty years and about one-third as much zinc. For lead and tin, however, consumption was no higher than in the previous decades.

Having shown that more and more mineral resources are being discovered all the time and that our reserves of scrap will continue to expand, I am now going to examine the trends in the use of metals to see whether any new developments are likely to upset the balance between production and consumption.

Trends in Consumption of Non-Ferrous Metals

Until 1940 all metals were plentiful, and so in the past trends in consumption were the results of advances in metallurgy and techniques of fabrication, and production and consumption were in the long run reasonably balanced; the rate of production can therefore be assumed to have reflected the demand for primary metal.

Fig. 1 shows world production over the past fifty years plotted according to weight. As will be seen, the production of copper and zinc has risen fairly persistently despite fluctuations, but that of lead, after rising to a peak in the middle twenties, declined, although it is now rising again. This decline may have reflected the growing importance of lead scrap as a source of supply. Copper has held first place since its production exceeded that of lead in 1929, but aluminium has risen steeply during the last ten years, and if its present rate of growth continues it will take first place within a few years.

The spectacular rise in aluminium during the Second World War and its continuing high level has been the most notable feature of the non-ferrous metals industry in recent years, and a rather better comparison between aluminium and other metals can be obtained by measuring their production on a volume basis. This is shown in Fig. 2.

It is not easy to assess the extent to which aluminium has made inroads into the fields previously held by other non-ferrous metals or steel, since, because of its light weight, it has opened up new uses for itself. Nevertheless, there can be no doubt that during the last twenty-five years the relative importance of the major non-ferrous metals has changed completely, and aluminium and possibly other new metals, such as magnesium and even titanium, can be expected to become more and more important in future. While much is spoken about titanium, it is too early yet to assess its future importance.

Factors Influencing Consumption

The extent to which a metal is used, while depending on properties and price, is influenced also by tradition and by

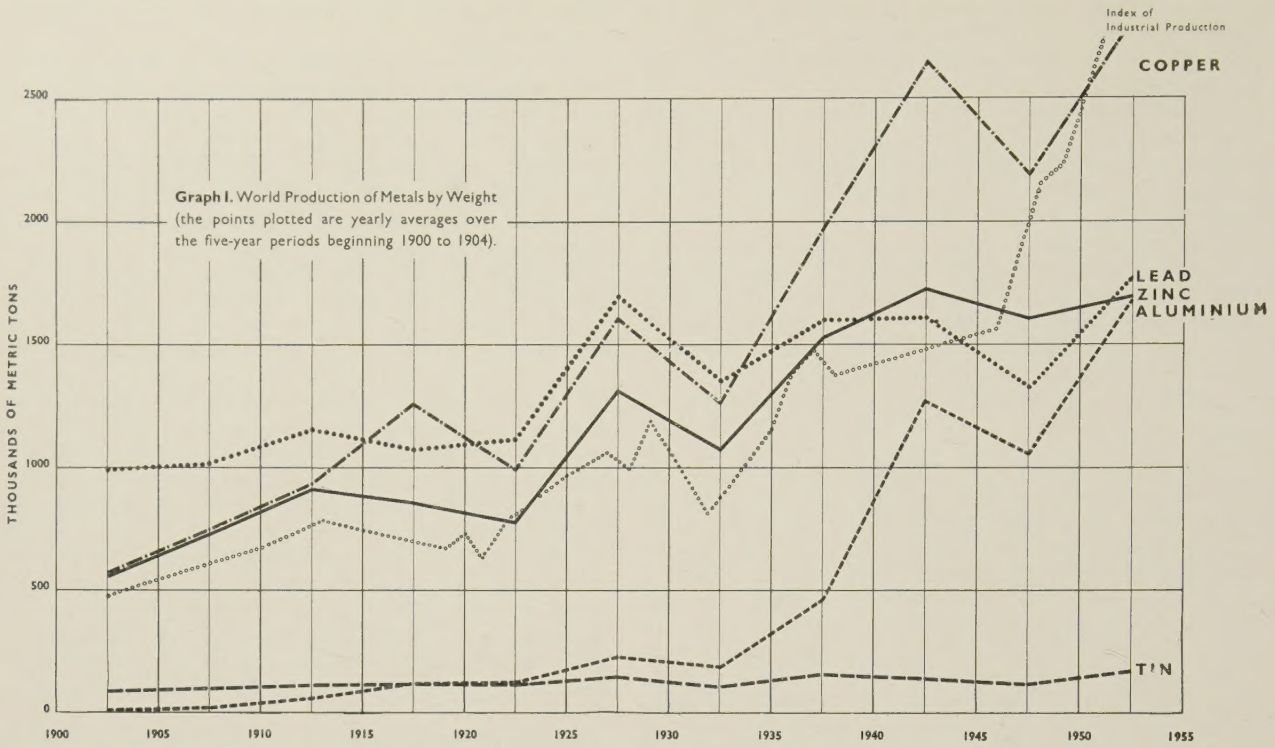


FIG. 1.

NOTE: The 1950–54 figure is based on estimates for 1953 and 1954.

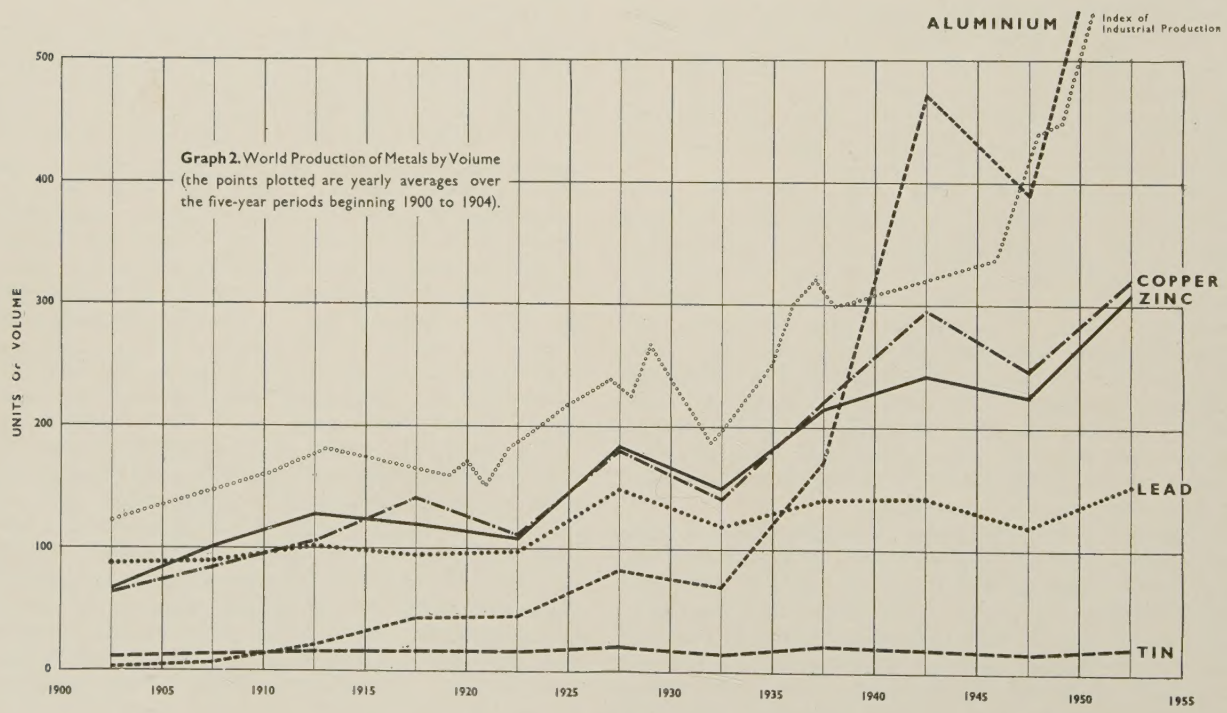


FIG. 2.

NOTE: The 1950–54 figure is based on estimates for 1953 and 1954.

advances in technology. Properties do not limit uses quite so much as might at first be thought, and, broadly speaking, for many purposes aluminium, copper, zinc, and their alloys are interchangeable, and the final choice is governed by price, which is therefore often decisive. Tin and lead, whose consumption has remained steady recently, have already suffered much by substitution, and for the present further substitution seems unlikely. Most metals, however, possess unique properties which determine some of their uses; e.g. aluminium for aeroplane construction, zinc for galvanizing, and copper for domestic electrical wiring—and these uses are hardly dependent on price.

Price

Until recently there was a fairly constant relationship between the prices of the major non-ferrous metals (see Fig. 3), and magnesium are abundant and cheap, and there are comparatively few producers; reduction plants are usually situated where there is cheap electric power, an important cost factor. Aluminium and magnesium also differ from the other metals in that nearly half the current production comes from plant less than 10 years old. Consequently the price at which the bulk of these metals can be sold is much the same all over the world.

The situation in the old metals is quite different, since there are many more producers, some with their own mines and some who buy concentrates from independent mines or treat them on toll; also the grades of ores vary, and some smelters have access to much cheaper power or fuel than others, so that costs differ from plant to plant. Therefore, broadly speaking, the price, except in times of government control, reflects the balance between production and consumption and

Graph 3. Yearly average British Metal Prices since 1913 (Pounds Sterling per long ton)

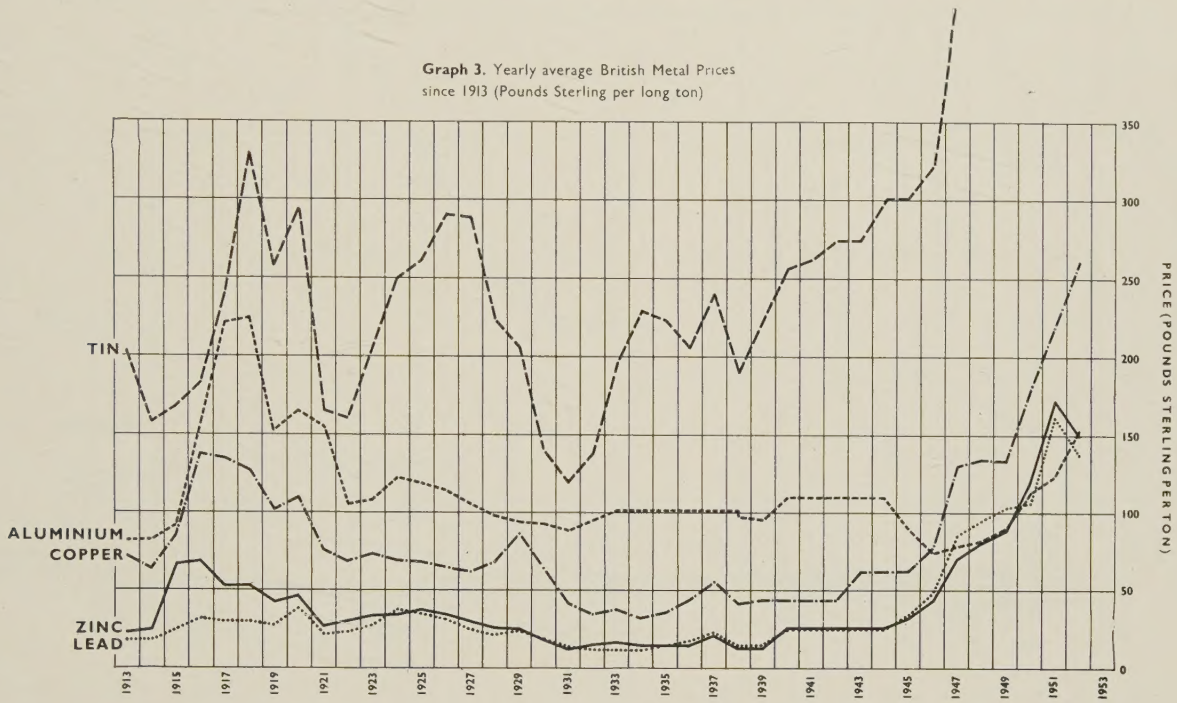


FIG. 3.

but the striking changes of the last few years lead us to wonder whether a new relationship has emerged. Between the wars there was a slow downward trend in the real prices of all metals when the slow increase in the value of money is taken into account. Thus metals seemed to be getting slightly cheaper as world production rose. Only in the case of tin were there fluctuations which did not conform to this pattern.

Since the war the relationship between the prices of the various metals, which previously had not altered much, has been quite different, only aluminium and magnesium having consistently kept at a price level not markedly different from their pre-war value. With the other metals, copper, zinc, lead, and tin, the prices have risen to unprecedented heights during the past two or three years, but all except copper have now dropped back to the level prevailing at the outbreak of the Korean war. Thus it is clear that different factors determine the prices of the old and new metals.

What are these factors? The raw materials for aluminium also the level of stocks. As consumption declines the price falls and eventually leads to lower production and vice versa. In practice there is a considerable time lag which causes the rises and falls to be accentuated by over-correction first one way and then the other. The fluctuations themselves are perhaps disturbing to some buyers, but facilities are available for "hedging" and, of course, the important factor is the average level of price over a period relative to the cost of competitive materials. Though higher prices eventually encourage production, they also cause consumers to seek substitutes, and a return to lower prices does not always lead to the substitutes being dropped. Violent swings are therefore damaging to the producers as well as to consumers.

The very fact that the prices of the old metals are affected by supply and demand makes it difficult to say just now at what level they will settle when the effects of rearmament and U.S. stockpiling are no longer felt. There is no doubt that costs have risen everywhere since the war, and in some cases the

present higher levels of production compared with pre-war may have been achieved only by using lower-grade ores, a factor which has not arisen in the case of aluminium. Therefore it seems likely that the higher prices of the older metals relative to aluminium since the war mark a permanent change, and that in future aluminium and magnesium are likely to remain cheaper by volume than copper, zinc, and lead (Fig. 4).

Sales Promotion

Another important factor affecting consumption, which is often under-estimated, is the extent to which research into uses and sales promotion help to increase the use of a metal. Such work has been a feature with aluminium and nickel, the only metals whose consumption everywhere is now much higher than 20 years ago—and it is worth noting that much of the increase in the use of aluminium took place before it was cheaper by volume than the older metals. In recent years the slow rise in the world consumption of copper, zinc, and lead (with no significant rise at all in most European countries since the war) has been due mainly to the expansion of their traditional uses with the increase in the world's industrial production. With more producers entering the light-metal field, internal competition between them may eventually lead to a reduction in expenditure on research and promotional work.

I think the difference in the make-up of the new and old industries has probably led to the difference in their attitude to increasing their sales. The newer metals, because their raw materials are abundant, have had to spend little money finding sources of supply, and so have been able to concentrate on developing and promoting sales. On the other hand, the older metals have done less to increase uses, and have been more concerned in seeking better sources of supply on account of the competition between individual producers and the incentives of high prices in times of shortage. While the outlook for the older metals is still good, there is no doubt that it has been affected to some extent by the vigorous steps the new metals have taken to increase their consumption. Nevertheless, quite remarkable results might be achieved if the older metals were to embark on schemes to promote sales comparable to those for aluminium and nickel.

Recent Developments in the Metal World

Since the war trade in metals has been greatly influenced by two factors. The first is the diversion, at a time of high normal consumption, of metals into the U.S. Government stockpile and then to rearmament. As a result nearly all metals have in recent years been scarce, and copper, zinc, and nickel have been subject to international allocation; in some countries certain of their uses were prohibited. The price of many metals, in particular copper, zinc, lead, and tin, consequently rose to unprecedented heights, though all have now returned to lower levels.

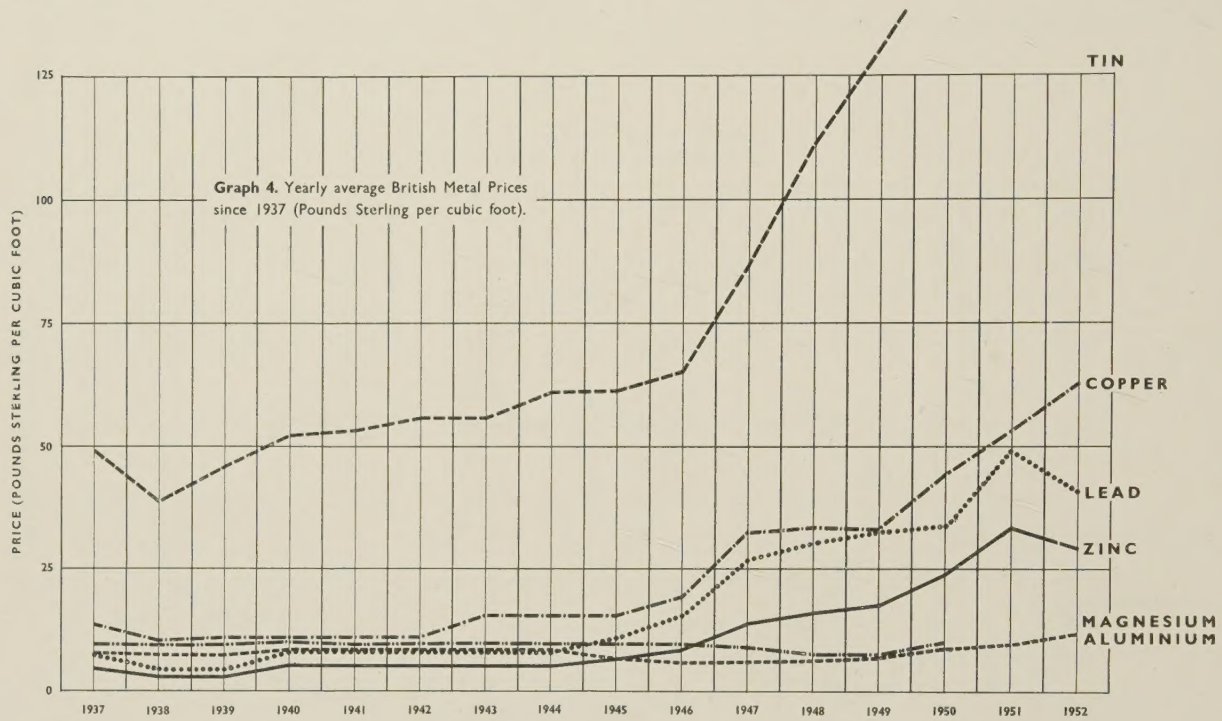


FIG. 4.

The second is the enormous growth of industry in the U.S.A. since 1940, first to make arms and then to meet the pent-up demand for civilian goods, and more lately for rearmament. This has meant that the United States, which was the largest exporter of most metals up to 1940, has now become the largest importer. Naturally, this led many people, both here and in America, to doubt whether the world production and resources would be able to meet the growing demand outside America as well as the new and expanding American import requirements.

These two factors are inseparable, since stockpiling, which has been largely confined to the United States and is intended to make good a loss of imports in times of war, has emphasized the fact that her requirements can no longer be met from

home production alone. Consequently she has taken steps to encourage foreign as well as home production.

Recent events suggest that world production and consumption of the metals about which we are speaking have now come into balance, except for nickel, which is still in short supply because of its exceptional uses in arms. The earlier predictions, that metal supplies might continue to be tight for many years, may therefore prove wrong, and perhaps we may now return to the pre-war conditions when most metals were in good supply. This certainly seems likely for the time being, since both the U.S. and this country are pursuing deflationary policies, and new metal production planned at the times of shortage and high price may continue to swell output. Such shortages as may arise in the near future will presumably be brought about only by political or strategic causes or, in the case of some metals, by further stockpiling.

TABLE II.—*Free-World Production and Consumption of Metals*

(Thousands of metric tons)

Area		Aluminium		Copper		Zinc		Lead		Tin	
		1938	1950	1938	1950	1938	1950	1938	1950	1938	1950
$ Area U.S.A.	P	130	650	620	960	470	570	340	390	...	...
	C	110	810	370	1290	380	880	370	800	50	70
	P – C	20+	160–	250+	330–	90+	310–	30–	410–	50–	70–
Total $ Area	P	200	1010	890	1230	880	1090	810	810	30	30
	C	110	890	430	1390	420	940	410	870	50	80
	P – C	90+	120+	460+	160–	460+	150+	400+	60–	20–	50–
£ Area	P	20	30	250	340	260	260	390	260	70	80
	C	70	180	280	430	250	330	400	230	20	30
	P – C	50–	150–	30–	90–	10+	70–	10–	30+	50+	50+
Other	P	310	240	700	940	540	700	490	520	70	60
	C	290	230	910	720	660	560	710	490	60	40
	P – C	20+	10+	210–	220+	120–	140+	220–	30+	10+	20+
Total	P	530	1280	1840	2510	1680	2050	1690	1590	170	170
	C	470	1300	1620	2540	1330	1830	1520	1590	130	150
	P – C	60+	20–	220+	30–	350+	220+	...	...	40+	20+

P = production. C = consumption. Aluminium = metal production. Copper = blister production. Zinc, lead, tin = mine production.

Table II gives the production and consumption of metals in the dollar, sterling, and remaining areas of the free world for 1938 and 1950. The figures of production for the different metals have been measured at what I believe to be their most significant points. Thus smelter production is given for aluminium and copper (i.e. blister copper or refined copper made by leaching), and for zinc, tin, and lead, mine production has been taken because there is a considerable international trade in their concentrated ores.

The figures show how great is the change in the United States' position from an exporter in 1938 to an importer of metals in 1950; however, the dollar area as a whole is well supplied with all metals except tin, but even so has to import copper and lead. The sterling area has a deficit of all metals except lead and tin. The figures also emphasize how great has been the growth in U.S. consumption compared with that elsewhere. It is therefore of interest to see where the greatest reserves of the various metals lie and also where production is most likely to be expanded in the near future.

Aluminium.—Some 30% of the most important single deposits of bauxite are in the Caribbean. Other important reserves are in India, the Gold Coast, Brazil, and Yugoslavia, but there are also substantial workable deposits in other countries. At present the principal reduction plants are in North America, which now produces over 80% of all the aluminium made, and in the next two or three years a further very substantial expansion in American production will take place. Thus the United States production will probably have expanded from 850,000 metric tons in 1952 to 1,400,000 metric tons in 1954, and that in Canada from 450,000 metric tons to 600,000 in 1954. The only notable project elsewhere is the Volta River scheme, which will not bear fruit before 1960. The world's dependence on dollar sources for aluminium is therefore likely to continue, although the United States will still have to rely to a small extent on imports for some years to come.

Copper.—The most important reserves of copper are in Canada, the United States, Chile, Northern Rhodesia, and the Belgian Congo. Since the rate of expansion depends to a great extent on price, it is difficult to predict what will happen in the immediate future. However, it seems clear that the greatest expansion will be in the United States, Chile, and Northern Rhodesia, although production will rise in other countries also. So the present distribution of production does not seem likely to change much in the next two or three years. Later on, production in the United States and Canada is expected to increase.

Zinc and Lead.—The reserves of zinc and lead are, like those of copper, well distributed throughout the world, and perhaps about a third are in the U.S.A. and Canada and about a quarter in Australia; many other countries contain important deposits. The rate at which the planned expansion in zinc and lead production will proceed depends on demand and price to a greater extent than with other metals. The main increases in zinc seem likely to be in Canada, the United States, Mexico, and North and Central Africa. So the present international distribution of production will probably not alter much, and the dollar area will be able to continue exporting substantial quantities of zinc. On the other hand, important changes can be expected in lead, since production is

declining in the United States, and is likely to increase in Australia, North Africa, Germany, and Canada.

Nickel.—The reserves of nickel-containing ores are of three types, and the largest measured reserves are the sulphide ores found in the Sudbury Basin in Canada, from which some 80% of the world's nickel has come since 1925. Recently other deposits have been found in Canada. Large deposits of silicate ores exist in New Caledonia and elsewhere, and there are also substantial deposits of nickel–iron ores in various countries, the largest being in Cuba; these constitute the world's main potential source of nickel, but recovery from them is still expensive. Projects for increasing production at existing and new sites in Canada are well advanced.

Tin.—The reserves of tin are less well distributed than those of other metals, and it is the only major non-ferrous metal of which there are no workable deposits in North America. The main reserves are in South-East Asia—about a quarter in Malaya and a sixth in Indonesia, with other sources in Thailand and Burma. There are also substantial deposits in China. The only other important known deposits at present being worked are in Bolivia, the Belgian Congo, and Nigeria. Since production has been running in excess of consumption for some time now—largely because of end-use restrictions in the U.S.A.—there is little interest in increasing production. Nevertheless, much of the world's supplies are strategically vulnerable, and so production may eventually be increased in Bolivia and the Belgian Congo.

This short review of reserves and proposed new production does, I think, show the great and growing strength of the North American continent as a producer of nearly all non-ferrous metals. Although this growth may well fail to keep pace with the increases in consumption, the likelihood of North America becoming more dependent on imports seems fairly remote, except perhaps in tin and possibly lead. We can, I think, conclude that no geographic or political area of the world is self-sufficient or likely to become so. Most manufacturing countries are also becoming more dependent on foreign primary metal. For these reasons it is in the best interests of the free world as well as ourselves that all countries should have free access to resources everywhere. The return to such conditions since the war has been slow, but progress has been more rapid recently. Nowadays the only remaining obstacles, apart from non-convertibility of currencies, seem to be the desire of some countries to maintain uneconomic but strategic production, and the wish of primary producing countries to fabricate more of their own metals and so lessen their economic dependence on manufacturing countries. All these factors which hinder the early return to complete freedom can be seen at work even in the U.S.A., the country which is perhaps most anxious to encourage economic co-operation in the free world. Some U.S. producers are also seeking special protection, since deposits now being worked there are poorer than in many other countries and wages are also higher.

Since these factors seem likely to operate for a long time, there are certain necessary steps that we should take if we are to be sure of improving our position. First of all we should encourage production in the sterling area. The proposals made at the recent Commonwealth Conference and for the Volta River aluminium scheme are steps in the right direction. However, before much progress can be made, many of our taxation laws, affecting mining and smelting companies with head offices in London, will need revision.

Secondly, we must make the best use of the only resource we have, viz. old scrap. Methods of collecting and separating scrap should be improved wherever possible, and techniques should be developed for working-up inferior grades of scrap to bring such material into Britain and so swell our resources.

Thirdly, we must keep in the forefront in methods of fabrication and must concentrate when we can on making goods with a high conversion value. In the absence of such steps, primary producers will naturally wish to fabricate more and more of the metal they make, and our own position will slowly deteriorate.

Much is heard about conservation these days, chiefly from America, and in the American sense, where conservation means using materials wisely, there is everything to be said for it. In England the word is too often taken to mean preservation, and so leads to restrictions and the use of substitutes, a policy which it would be foolish to follow as long as the world's supply of metals is adequate to satisfy all the demands of industry.

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SOME ELEMENTARY THERMODYNAMICS OF REFINING

By V. KONDIC,* B.Sc., Ph.D.

THE fundamental problem of refining is that of separating elements one from another. Chemical thermodynamics provides general laws whereby their separation or combination can be analysed and studied for a given set of working conditions.

Methods of Refining

Methods of separation can be grouped under three main headings:

(a) *Physical.*—This group covers a number of different methods, all based on the phenomena either of evaporation or of segregation. If, in a general case, we have to separate a mixture (or solution, or compound) AB into its components A and B, according to the relation:

$$(AB) \rightleftharpoons A + B,$$

then in the evaporation method:

$$(AB)_L = A_V + B_L,$$

while in segregation:

$$(AB)_L = (aB)_L + (bA)_L,$$

where L is liquid and V vapour, and a and b imply small concentrations of A and B, respectively.

(b) *Chemical.*—The basic feature of this method is the addition of a third element C, to combine preferentially with the undesirable element in the mixture:

$$AB + C = A + BC$$

(c) *Electrochemical.*—Here, electrical energy is used to separate the elements, which are held in a suitable solvent:

$$AB + \text{solvent} = A^+ \text{ (cathode)} + B^- \text{ (anode)} + \text{solvent}$$

The common feature of all these methods is that a certain change of energy is involved in separating A from B. By means of chemical thermodynamics it is possible to relate such energy changes and then to derive further information of interest, e.g. the degree of separation, or the effect of temperature and pressure changes on the outcome of the refining process. As the chemical method of refining is that most commonly used, it will be taken as an illustration, but the same principles hold for the other methods.

Heat-Energy Laws

Chemical reactions afford an example of processes in which one type of distribution of energy of a substance is transformed into another. Experiments designed to study such changes normally include measurement of the properties of the substances before and after the change, and from these data the change in energy can be evaluated.

The total energy E of a substance can be expressed as the sum of all different types of energy that can be experimentally distinguished: chemical energy C, heat energy H, work energy W, potential energy P, and others.

$$E = C + H + W + P$$

In chemical reactions it is the heat energy H and the work energy W which are mainly affected and are measurable in the change. In order to measure energy changes, it may be necessary first to establish the units for measuring different properties of the substance. The properties generally selected are temperature, pressure, volume, and mass (or concentration). Alternatively, an arbitrary unit for measuring the energy change itself may be adopted. For example, H can be measured in calories. The heat energy of any other substance is then obtained by direct comparison with the standard. The heat-energy change is affected by the imposed condition of the test, which for more practical application is that of constant pressure. Under these conditions the total energy change of a substance in a chemical process, ΔE, is identical with the heat-energy change ΔH. For a unit mass of a substance the heat-energy change is defined as the specific heat, C_p. It is found experimentally that the value of the specific heat varies with temperature. This relation is generally expressed by an empirical equation of the type:

$$C_p = a + bT + cT^2$$

where a, b, and c are constants and T the absolute temperature. The heat-energy content of a unit mass of a substance at any given temperature can therefore be obtained by integrating the specific-heat values over the desired temperature range:

$$H_T = \int_0^T C_p dT = \int_0^T (a + bT + cT^2) dT$$

In chemical reactions we are mainly concerned with heat-energy changes resulting from the reaction process. It is convenient for the purpose of tabulating such data to assume that, at a certain level, e.g. 25° C. and 1 atm. pressure, the heat content of all chemically pure substances is zero. The heat of reaction measured is then identified as the heat content of the product formed by the reaction:

$$A + B = AB + Q \text{ cal.}$$
$$\Delta H \equiv H_{AB} \equiv Q \text{ cal.}$$

This heat also varies with temperature, and can be found from the specific-heat values of the reactants and the products:

$$H_T - H_0 + \int_0^T \Delta C_p dT$$

At one time it was thought that if the values of the heats of reaction of various substances were arranged in a table, comparison on a weight basis would indicate the stability of any given compound, i.e. that the substance giving rise to the largest heat change, or whose heat of formation was the highest, would be the most stable.

$$A + B = AB + Q_1 \text{ cal.}$$
$$A + C = AC + Q_2 \text{ cal.}$$
$$A + D = AD + Q_3 \text{ cal.}$$

If $Q_3 > Q_2 > Q_1$, then AD is more stable than and will form preferentially to AC, which in turn is more stable than AB.

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The reasons why this argument is not necessarily always correct are explained below.

Directions of a Chemical Change

A chemical reaction does not generally proceed to completion, and some of the original reactant may still be present. The reaction proceeds in one direction, but the products formed decompose again until a balance of equilibrium is attained:

$$A + B \rightleftharpoons AB$$

One of the purposes of chemical thermodynamics is that of establishing a criterion for use in predicting first the direction of the reaction and then the extent to which it will proceed in that direction.

The extent to which a reaction proceeds can be suitably expressed by means of a ratio generally known as the equilibrium constant K. The units employed to express K may vary according to experimental convenience, but in general these units can be related to the active mass (or activity) of all the substances participating in the reaction:

$$K = \frac{a_{AB}}{a_A \times a_B}$$

Here, a may be equivalent to wt.-%, molecular fraction, units of pressure, or other units. If the value of K obtained is large, then the reaction moves to the right and vice versa.

The value of K can be determined experimentally for most chemical reactions, for given conditions of concentration, pressure, and temperature. It would be convenient, however, to be able to calculate values of K from already known or established properties of substances, for two reasons. First, it would be possible to predict the course of the reaction without resort to sometimes very difficult and laborious experiments, and secondly, values of K could then be deduced for other sets of experimental conditions. Chemical thermodynamics sets out to provide an answer to these problems, by establishing the laws governing the energy changes involved in chemical reactions.

One of the general observations made regarding processes involving changes in heat energy concerns the unidirectionality of such changes when they occur spontaneously. For example, heat always flows away from a body at a higher temperature to that at a lower temperature. It was therefore desirable to find a property which could uniquely describe the "quality" of the energy of a substance, i.e. whether the energy would tend to change spontaneously under a given set of conditions. This property has been found to exist, and has been termed the entropy S. Its numerical value, at constant pressure, can be obtained for any substance at a given temperature by dividing the heat content by the temperature:

$$S = \int_0^T \frac{C_p dT}{T}$$

If values of the change in this property are obtained for all substances taking part in a spontaneous reaction, including the surroundings, then for a constant energy there is a net increase in entropy:

$$\Delta S_E \geq 0,$$

where an increase in entropy corresponds to a spontaneous change and equality to zero corresponds to equilibrium or absence of any change.

As well as giving the measure of spontaneity of a chemical change, the entropy has a more practical application. In all processes involving heat-energy changes, a part only of the available energy present can be converted, at a given pressure and temperature, into useful work. This is known as the available or free energy G. It is obtained by deducting from the total heat energy H the non-available or bound energy TS, i.e. the product of entropy with temperature:

$$G = H - TS$$

The natural tendency is for all processes to proceed in the direction of maximum stability, which is that of the minimum free energy. When several substances are taking part in a spontaneous reaction, then there will be a decrease in the free energy:

$$\Delta G \leq 0$$

If there is no change, or equilibrium prevails, then:

$$\Delta G = 0$$

In order to test whether a chemical reaction would proceed spontaneously, the free-energy change is obtained by subtracting the free energy of the reactants from that of the products:

$$\Delta G = G_{AB} - G_A - G_B$$

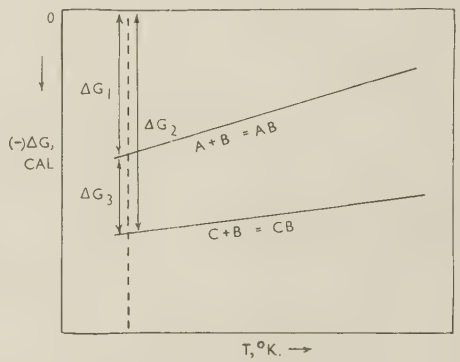

FIG. 1.—From the graph it can be seen that CB is more stable than AB, i.e. that C could be used to reduce AB:

$$(-)(A + B) = AB, \Delta G_1 \quad . \quad . \quad . \quad . \quad (1)$$
$$(+)\ C + B = CB, \Delta G_2 \quad . \quad . \quad . \quad . \quad (2)$$

by subtracting (1) from (2) we have:

$$C + AB = A + CB, \Delta G_3$$
$$\Delta G_3 = \Delta G_2 - \Delta G_1 < 0$$

By a procedure similar to that used in tabulating the heat contents of substances, tables of free energy for a set of standardized conditions can be obtained. As chemical reactions can be carried out at any given temperature, it is desirable to quote free-energy values as a function of temperature. In general, these values can be represented by an equation of the type:

$$\Delta G_T = A + BT \ln T + CT$$

By means of such equations the free-energy change involved in a chemical reaction at a given temperature can be obtained. To simplify such calculations, the free-energy changes can be plotted graphically, as in Fig. 1, the result in many cases being a straight line.

Such graphs can be plotted to cover the formation of oxides, sulphides, carbonates, or other compounds, and provide a most useful tool for comparative studies of chemical reactions.

Their value is not, however, confined to predicting the

tendency of a reaction, for the free-energy changes read from the graph can be used to calculate the equilibrium constant for different sets of conditions.

Free-energy change represents the maximum work that can be obtained by carrying out any particular process. In a chemical reaction this is the sum of all the work involved in transforming the products and reactants from a given initial state (1) to the end state (2):

$$\Delta G = RT \ln \frac{a_1^2 \times b_1^m}{c_1^p \times d_1^q} - RT \ln \frac{a_2^2 \times b_2^m}{c_2^p \times d_2^q}$$

If the initial state is chosen such that the active masses of the reactants and products are all unity, then a free-energy change is obtained which is defined as the standard free energy ΔG_0:

$$\Delta G_0 = - RT \ln \frac{a^l \times b^m}{c^p \times d^q} = - RT \ln K$$

This is one of the most important uses of the free-energy values, as it enables us to calculate the value of the equilibrium constant. The application of this relation to the practical problems of the refining of metals depends first upon the availability of free-energy data and then on a knowledge of the active masses (activity) of the components taking part in the reaction.

THE PREPARATION OF REFINED COPPER AND COPPER-BASE ALLOYS FROM METAL SCRAP

By H. J. MILLER,* M.Sc., F.I.M.

THE recent report of the Paley Commission published in the U.S.A. comments that the collection, recovery, and reclamation of once-used metals is haphazard in the extreme. While this may be true of certain metals, it does not apply to copper and copper alloy materials, the utilization of which mostly proceeds in a satisfactory manner. Criticisms might, however, be levelled in regard to facilities for the collection and recognition of copper-containing scrap, the main difficulty being that the copper frequently forms only a small proportion of the total metal content. It is thus a question of whether it is economic to make the separation. Another criticism is that in processing the recovered scrap there is a loss of certain minor metals. However, there is undoubtedly a most effective utilization of the copper content.

Types, Sources, and Quantities of Scrap

Three different types of scrap are involved: (i) old or demolition scrap; (ii) process scrap from the engineering industries; and (iii) the waste products of the metallurgical industries such as slags, residues, and ashes.

Old scrap is handled for the most part by scrap-metal merchants, although there has always been direct competition by users for certain categories such as telephone-, and trolley-wire scrap, railway-firebox scrap, ships' castings, &c. In the laborious operations connected with sorting and identification, the scrap-metal-merchant industry plays a most useful part, and tribute should be paid to its efforts in fitting scrap metal to suit particular customers' requirements.

Process scrap from the engineering industries is only partly handled by scrap-metal merchants, a large quantity frequently being returned direct to metal fabricators under contra-account or similar arrangements. Provided that the engineering industries are careful in regard to segregation and non-contamination, the return direct to fabricators functions satisfactorily, but if mixing and contamination occur, then scrap-metal merchants can often supply a useful market outlet; although this, of course, involves undesirable "down-grading" of scrap, whereas from the point of view of prices and of national economy, the desirable condition is that of "up-grading", a term much used in the last war period and in subsequent times when the whole of industry has been exhorted to make the best use of metals.

The quantity of copper-containing scrap coming forward from all sources amounts to almost 40% of the total copper supplies; this gives a measure of the importance of scrap in the national picture. Of this percentage the division between old scrap and process scrap is not always clear. The statistics of the U.S. Bureau of Mines make a distinction, which may not be strictly accurate, but other reporting statistical organizations do not attempt to divide the two types. Apparently the proportions of "old" and "new" vary widely, though strangely enough the total quantity seems to be fairly stable. The Bureau of Mines statistics show the outlets of copper which is refined and re-emerges again, as virgin copper, the amount absorbed direct by fabricators and foundries, and the amount that passes through the ingot trade.

The amount of process scrap coming forward at any given moment is fairly definitely related to the industrial activity existing a short time before. The amount of old scrap is not so related, unless reference is made to the industrial activity of a much earlier period. This proves difficult because some products have a life of only a few months, while others have an extremely long life. Perhaps on the average it might be taken that old scrap bears a relation to the industrial activity of 20 years previously. However, many other factors influence the supply, chief among them being questions of redundancy, facilities for replacement, and the general level of metal prices. Under some conditions old scrap becomes available in very large quantities, totally unrelated to the ability of the industry to absorb it at the time; as it has to find a market at any price, it thereby influences price levels.

Applications of Scrap

In considering scrap uses it is necessary to distinguish between metallic and non-metallic types, for whereas the former can be used direct, the latter must be subjected either to preliminary segregation or to smelting operations.

There are obvious economic advantages in utilizing the metallic types direct. The first step is the recognition and classification of scrap according to its composition and the kind of product to which it is fitted. Scrap comes forward from about 200 different compositions of copper and copper alloys; it cannot be grouped as widely as this, but metal merchants frequently segregate it into about 30 different classifications.

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The markets available are broadly:

(*a*) Gun-metal castings and ingots.
(*b*) Brass castings and ingots.
(*c*) The extruded brass industry.
(*d*) The wrought α-brass industry.
(*e*) Fire-refining for commercial copper.
(*f*) Smelting to give crude copper, which may be subjected to electrolytic refining to produce high-grade copper.

Various pretreatment processes may be applied to fit the scrap for use direct. They are essentially simple, such as the removal of water and oil by centrifuging in the case of swarf, or by passing through a furnace on a vibrating-plate type of conveyor in the case of all forms of light scrap; the removal of iron particles by magnetic machines; the briquetting of swarf; the baling of webbing scrap, &c.; the "masticating" of curly turnings, which are difficult to use direct; the stripping of cables; solder-sweating operations, e.g. on radiators to separate the white metal from the copper or brass cores. These are only examples, and special processes are often developed for particular types of material. Quite frequently a combination of the processes mentioned can be adopted with beneficial results to quality, efficiency of melting, reduction of metal loss on melting, or other factors.

(a) *Gun-metal Castings and Ingots.*—It is not customary to employ much gun-metal scrap direct for the production of castings, because it is not easy to control composition sufficiently accurately, the scrap is frequently of an unsuitable size, there is a tendency to absorb gases during melting, and for other reasons. Instead, gun-metal scrap is purchased by ingot manufacturers who carry out refining and blending to arrive at ingots of the compositions covered by B.S. 1400. The chief standard types are 88 : 10 : 2, 86 : 7 : 5 : 2, and 85 : 5 : 5 : 5 copper–tin–zinc–lead alloys with fairly liberal margins on impurities. Thus, scrap containing any of these elements can be blended to give one or other of these compositions. Frequently the zinc content of the initial charge is on the high side, and is reduced to the necessary figure by oxidation; the zinc oxide may be recovered by collection in bag-houses, though this is not always the case, and hence a large industrial loss of zinc is experienced. In the oxidation process, aluminium, iron, and certain other impurities are removed almost entirely by passing into the slags; this is particularly necessary in the case of aluminium, probably the most deleterious impurity which can be present in gun-metals for casting purposes.

(b) *Brass Ingots and Castings.*—The trade practices are much the same, and again strongly oxidizing conditions are current during the melting and refining for ingot-metal production, with an inevitable loss of zinc.

(c) *The Extruded Brass Industry.*—This provides the largest single outlet for copper and copper alloy scrap. Melting is usually conducted direct in furnaces of 1-ton capacity, so that manufacturers can even out fairly well variations existing in the parcels of scrap; it is unusual to ingot metal before billet casting except when contaminated scrap has to be dealt with. From the metallurgical aspect it is necessary for the billet castings to comply with specifications for the major elements and impurities; in addition, particular control must be exercised over the bismuth and antimony contents, owing to their pronounced deleterious effects. The general practice is to restrict the use of scrap to such grades as B.S. 218 (hot-stamping brass) and B.S. 249 (free-machining brass) and the commercial variations of these leaded brasses.

(d) *The Wrought α-Brasses.*—Composition must be controlled to a much greater extent, and only selected material, such as wrought copper and brass scrap of definite known composition, can be used. Lead must be restricted to about 0·01–0·02% when hot rolling, but greater amounts, as recorded in B.S. 265, 266, and 267, may be present when cold rolling. Control of iron and other impurities, which affect recrystallization and grain-growth characteristics, is essential.

(e) *The Fire-Refining of Copper.*—Five different types of tough-pitch copper are recognized by B.S. specifications. For the three lower grades, with copper contents of 99·85%, 99·7%, and 99·5%, quite large amounts of copper scrap can be employed. For the two high-conductivity grades there are serious limitations on the types of scrap which can be used, mainly because of adverse effects on conductivity; for instance, 0·005% nickel is about the maximum that can be tolerated. Thus in effect it is stipulated that only clean copper scrap shall be absorbed direct in fire-refining for these grades. When fire-refining mixed charges containing scrap for the lower grades of copper, i.e. those which do not have to conform to the conductivity standard, the refining operations may be conducted so as to reduce arsenic, lead, and tin to quite small amounts. However, the removal of substantial quantities of lead and tin is costly, because large quantities of copper also pass into the slags, thereby involving high costs for subsequent recovery by smelting. While arsenic may be reduced to extremely low percentages by the use of alkaline slags, this is not usually necessary, as the arsenic tolerance in the specifications is sufficiently liberal to cover the average content of the initial scrap. Easily oxidizable elements, such as zinc, aluminium, and iron, pass into the slags readily. Nickel, as already mentioned, is a persistent element, and this applies also to bismuth, selenium, and tellurium, and to a lesser extent to antimony, elements which for all practical purposes are not reduced in the normal fire-refining cycle.

(f) *Smelting.*—This market as previously defined utilizes the scrap which cannot be absorbed direct in the metallurgical industries, either for quantity reasons or because of its low grade. The processes to which such scrap is subjected belong more strictly to the field of smelting operations, as carried out on residue materials and will be considered under that heading. It may, however, be pointed out that during the last 20 years the copper content of scrap material passing through U.S. smelting and refining plants has ranged between 20,000 and 90,000 tons per year, with an average of about 50,000 tons. This corresponds to something like 5% of the total copper supply in the U.S.A. and it gives a measure of the amount included in this category. This latter percentage figure is probably typical of other industrial countries.

Treatment of Residues and Scrap by Smelting and Refining

Some grades of residues and slags may be accorded preliminary crushing and either wet or dry milling, screening, and classification processes in order to recover the metallic fractions, which may be returned for melting in conventional furnaces. Such processes are purely optional, and under some conditions obviously offer financial advantages.

For the most part, however, slags and residues are treated by smelting in a blast furnace for recovery of either "black copper" of "matte copper"; the latter involves smelting with pyrites to provide the necessary sulphur content. The advantage of matte smelting is that cleaner slags result, but there is considerable argument in regard to the economics of the two methods. Whichever product is obtained there must be a further main processing operation, either in a reverberatory furnace or in a converter, to oxidize sulphur, iron,

tin, lead, and other impurities. Metallic types of scrap are usually introduced into the smelting cycle at this stage, though in some smelting plants brass scrap, &c., is charged to blast furnaces smelting for black copper. In the case of both the reverberatory and converter processes the underlying principle is that of oxidation, whereby the impurities either pass into the gases or enter into the slags. The gases may be passed through electrostatic precipitators or bag-houses for collection of oxides, from which it is possible to recover zinc, tin, and lead. The slags must always be re-cycled through a blast furnace for recovery of their copper content. From both reverberatory and converter furnaces the grade of copper obtained has a copper content of from 96 to 99%, and this may be transferred in a molten or cast condition to another reverberatory furnace for casting into anodes. Alternatively, the copper can be shotted, as required, for instance, in the manufacture of copper sulphate, which provides a most important commercial outlet for such copper.

For electrolytic refining, the quality of anodes should reach at least 98·5% copper content when adopting the conventional electrolytic tank-house practice with sulphuric acid solutions of about 15% strength. Electrolytic refining is too specialized a subject to deal with adequately in this paper, but the process must be carefully controlled so as to obtain a high grade of copper cathode; the impurities either pass into solution or are deposited as slimes in the bottom of the tanks.

A modified electrolytic-refining process developed by Lewin employs anodes having an approximate composition of copper 85–95, tin 2–8, lead 2–5, and zinc ~2%. The aim in this case is to retain the tin and lead in the copper and not to separate in gases and slags as described previously. The Lewin process operates with a solution of lower acid strength, chosen to favour the settling of tin and lead as slimes. There is a much higher power requirement. The process has many difficulties and is costly, especially in regard to treatment of solutions and recovery of tin and lead from the slimes, though perhaps not more so than the alternative of continuing smelting to a further point and recovering tin and lead from the dusts.

Other processes for purifying very low-grade material have been suggested, and last year details were published of a process perfected by the Chemetals Corporation in the U.S.A., by which it is suggested that brass-type scrap material—not copper—should be leached in an ammoniacal solution with continuous oxidation of the latter. The whole of the copper and zinc is thus dissolved, leaving tin, lead, nickel, siliceous matter, &c., as a residue, which is removed by filtration. The clear solution of copper and zinc is heated in an autoclave to 150° C. at 900 lb./in.^{2} pressure, and carbon monoxide gas is passed through the solution, thus precipitating the copper as a fine powder. This is filtered, washed, and dried and subjected to further metallurgical treatment; the solution is treated for the recovery of the zinc in the form of chemical salts. While a pilot plant has been described, it does not seem that a commercial plant has yet been erected to operate this process. However, it represents an interesting technical development and must prove itself in competition with the other processes mentioned.

REMELTING AND REFINING OF ALUMINIUM ALLOYS

By E. SCHEUER,* Dr.rer.nat.

To throw the subject of this paper into its proper perspective, some data are first given showing the quantities with which

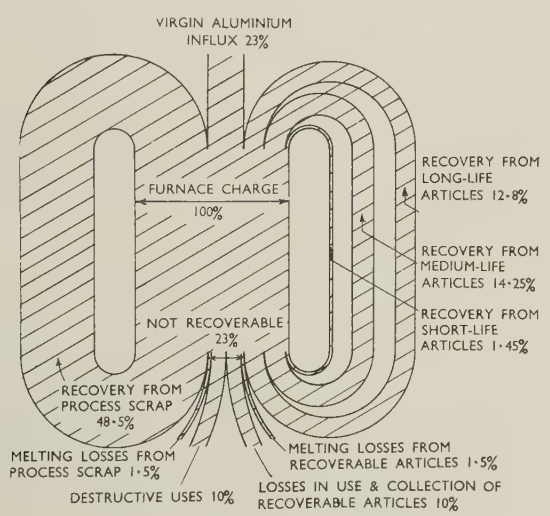
VIRGIN ALUMINIUM INFLUX 23%
FURNACE CHARGE
100%
RECOVERY FROM LONG-LIFE ARTICLES 12·8%
RECOVERY FROM MEDIUM-LIFE ARTICLES 14·25%
RECOVERY FROM SHORT-LIFE ARTICLES 1·45%
NOT RECOVERABLE 23%
RECOVERY FROM PROCESS SCRAP 48·5%
MELTING LOSSES FROM PROCESS SCRAP 1·5%
MELTING LOSSES FROM RECOVERABLE ARTICLES 1·5%
DESTRUCTIVE USES 10%
LOSSES IN USE & COLLECTION OF RECOVERABLE ARTICLES 10%

Fig. 1.—Illustrating Metal Losses and Recovery in Production of Aluminium Articles. (*After K. Schneider.*)

the aluminium remelting industry deals and their relation to the whole material throughput of the aluminium industry.

Fig. 1 illustrates in very general terms what happens to the metal charged into the furnaces for the production of all aluminium articles.[1] The diagram is constructed on the assumption that production and consumption have been static over a lengthy period, so that a stationary condition balancing the irrecoverable losses by influx of new virgin metal has developed. If this is the case, only 23% on the average of the metal charged into the melting furnaces is new metal making up for irrecoverable waste by oxidation, dispersal, and destructive uses. (This figure is roughly confirmed by Korn.[2]) About 28·5% is recovered from aluminium articles of all kinds discarded after various periods of use. (E. H. Jones [3] obtains figures of between 29 and 60% for recovery, from used articles, of copper, zinc, lead, tin, and antimony.) 48·5% returns to the furnace as cuttings and rejects from various stages of fabrication, generally called "process scrap".

In dealing with the aluminium remelting industry of today, two major corrections have to be applied to this picture.

(1) Not all of the recirculating 77% of the metal charge is passed through the remelting industry before being re-used. A substantial part of the 48·5% process scrap is clean and compact enough to be melted without special treatment simply as ingot metal. Perhaps one half of the 48·5% might go back to the furnace in this way. This would leave a total of 77 — 24 = 53% for treatment by the remelting industry.

(2) We are still living in a period of expanding aluminium consumption. The recovery of aluminium from discarded

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articles is therefore not related to *today's* production volume but to the much smaller volume of consumption at the time—anything up to 20 or 30 years ago—when the articles now discarded were produced. Consequently, the relative input of new metal at present will be larger than the 23% indicated.

In times of receding aluminium consumption a percentage of scrap higher than is now the case would be available, and this has in fact occurred in the past during periods of temporary depression in the trade.

The actual figures show that, excluding the heavy process scrap which calls for no special treatment and averaging over the whole production, very roughly 30% of scrap is at present separation. In the case of aluminium scrap it is, with the methods at present available, so expensive to extract pure aluminium from alloys that the process of recovering aluminium metal from scrap is mainly a blending process, so far as composition is concerned. Certain metallic constituents or impurities, such as magnesium, are, however, controlled by typical refining operations. Apart from this, the object of the refining part of the operations is to prevent pick-up of constituents from mechanically admixed foreign material, and to eliminate oxides formed during melting and other non-metallic contaminations. Gas is a non-metallic impurity which has to be avoided or eliminated.

TABLE I.—*Comparison of Primary and Secondary Consumption* *

(Thousands of metric tons)

	1948			1949			1950		
	Primary p	Secondary s	$\frac{s}{p}$, %	Primary p	Secondary s	$\frac{s}{p}$, %	Primary p	Secondary s	$\frac{s}{p}$, %
United States	622	261	42	578	164	28	817	265 †	32
Total O.E.E.C. Countries	375	163	43	350	140	40	391	152	39
United Kingdom	176	70	40	181	70	39	184	70	38
France	79	25	32	48	20	42	55	20	36
Germany	33	42	127	36	23	64	48	30	63

* Sources: for European countries—O.E.E.C. reports. For United States figures—Bureau of Mines. United States secondary figures calculated as secondary recovered as metal or alloys plus imports of scrap and remelted ingot.

† This figure is a preliminary estimate.

incorporated into the total aluminium production. Table I illustrates the ratio of secondary and primary metal in the consumption of various countries after the war.[4]

Table II gives figures showing the percentage of scrap incorporated into the aluminium products of the United Kingdom based on the statistics of the Ministry of Supply. It

TABLE II.—*Remelted Aluminium Incorporated in U.K. Aluminium Products* *

(Thousands of long tons.)

		Year					
		1947	1948	1949	1950	1951	1952 †
Total fabrication		176·1	230·5	227·9	238·4	282·0	297·0
Total despatches of ingot.	Virgin	159·2	173·7	178·6	181·4	202·9	238·0
	Remelted	107·5	80·1	68·8	93·8	132·5	117·0
Percentage of remelted metal in products.	Wrought	27·9	9·2	10·0	11·1	15·5	11·4
	Cast	81·3	79·9	84·2	86·9	78·4	74·7
	Destructive uses	69·6	72·2	71 8	64·9	67·7	70·8
Overall		40·2	26·4	27·5	31·1	33·5	30·8

* Source: Ministry of Supply Statistics.

† Estimated from figures January–September.

may be mentioned that in 1951, of the fabricated products, about 73% of the tonnage represented wrought products (including 5% foil), 26% cast products, and 1% destructive uses.

The estimated annual output in 1952 of the aluminium remelting industry was roughly 90,000 tons, worth about £12–15 millions.

Raw Material Treatment

For economic reasons there is rarely any point in separating the components of alloys if the material can be used without

An examination of the types of material available for the production of remelted aluminium, as set out in Table III, will illustrate the possibilities of contamination.

How far is it desirable, possible, and economical to remove the mechanical admixtures and separate the various aluminium

TABLE III.—*Raw Material for Remelted Aluminium Ingot*

Designation	Description	Typical Contamination
	A. *Residues from Aluminium Fabrication*	
Foundry residues.	Dross, spillings, fettling scrap.	Oxide, sand, iron from mould pins.
Fabrication residues.	Forging flashes, sheet trimmings, cuttings, ends from extrusion and drawing operations, turnings, millings, borings.	Steel and other heavy-metal particles, small tools, lubricants, fibres from rags.
	Grindings.	Abrasive particles from grinding wheels.
	Sweepings.	Sand and foreign-metal particles.
	B. *Discarded Articles*	
Essentially pure aluminium.	Chemical plant.	Welding alloy.
	Overhead, transmission cables.	Steel core wire, clamps, &c.
	Pots and pans. Vehicle bodies.	Handles, bolts, &c., of alloys or foreign metal, plastics.
	Foil and packages.	Paper or plastic backing, paint, lead and tin foil.
	Cast armatures.	Steel laminations.
Essentially wrought alloys.	Aeroplane fuselages, propellers and wings. Buildings (unavailable for some time).	Bolts and other parts of steel and other foreign metals, electric wiring, paint, plastics, rubber.
Essentially cast alloys.	Motor castings, pistons, engines.	Parts of foreign metal, paint, grease.
Mixed.	General engineering scrap.	Anything.
	C. *Virgin Aluminium*	
	Ingots.	...

alloys before melting? This question leads to very complex considerations, which will be cut short by describing the procedure generally followed.

The ideal raw material for production of remelted ingot would, of course, be scrap parcels containing only one alloy each. This can be achieved in a limited number of cases. The next best solution is to obtain scrap segregated into groups which include only components and amounts not interfering with each other's usefulness as alloying constituents. During the war such a segregation schedule was put forward by the Government in co-operation with the remelting industry, and this is reproduced in a simplified form in Table IV. In the

TABLE IV.—*Segregation Groups of Aluminium Alloy Scrap. Based on Segregation Schedule*

Group No.	Designation	Typical Alloys
1	Pure aluminium	Aluminium 98, 99, 99·5, 99·7-99·95%
2, 2a, 2b	Duralumin	Cu 1–5%, Si 0–1·5%, Mn 0–1%, Mg 0–1%
3	Aluminium–magnesium alloys	Mg 1–10%, Mn 0–0·5%
4–5	Aluminium–copper–nickel alloys	Cu 1–5%, Ni 1–2·5%, Mg 0–2%, Si 0–3%
6	Aluminium–copper alloys	Cu 6–12%, Si 0–2%
7	Aluminium–zinc alloys	Cu 0–3%, Mg 0–3%, Si 0–2%, Zn 5–13%
8	Aluminium–silicon alloys	Cu 0–1·5%, Mg 0–1%, Si 5–13%, Mn 0–1%, Ni 0–2·5%
9	Aluminium–copper–silicon alloys	Cu 0–8%, Si 2–6%, Zn 0–4%

case of large-scale use of aluminium, it is possible for process scrap of single alloys to be strictly segregated where it arises. In dismantling assemblies, e.g. motors, a considerable extent of alloy segregation can be obtained with the larger parts. In the case of smaller-scale users, and of sorting mixed parcels of scrap, segregation into groups is a more practical solution. Mixed parcels of small parts cannot even be sorted into groups economically, and must be used as they are. They are consequently lower in value.

For the various materials and complex structures received by the remelting plants, a number of preparation processes are in use. The most obvious one is hand-sorting. This often goes together with dismantling, as far as economical considerations allow this expensive operation. First the sorter removes foreign material; he also to a certain extent segregates alloys or groups of alloys. In this he is guided by information on the practice of the relevant section of the engineering trade, and further by quick and simple chemical, physical, and mechanical tests carried out partly on the spot but preferably under the supervision and with the co-operation of the laboratory.[5, 6]

The more efficiently this part of the work is developed, the higher the value of the sorted material. Recently, ingenious instruments have been devised to include electric conductivity and galvanic potential among the properties available for sorting tests.[7–9] This can be expected to be of value in specialized cases. Nothing has, however, been so far published or become known about industrial application of these methods in routine sorting.

If the fragments are too small to make hand-sorting economical, magnetic admixtures such as iron and steel can still be removed at low cost by means of magnetic separators.

Turnings need further treatment before magnetting, namely crushing, to break up long chips and spirals which would obstruct the flow in the mechanical-treatment plant, and drying (sometimes preceded by centrifuging) to remove oil and moisture. A train of appliances for treating turnings is represented in Fig. 2. It comprises hammer mill crusher (underground), drier, and magnetic separator.

Dross and spillings are given mechanical treatment to remove the oxide and other non-metallic material. Generally they are crushed in a ball mill where the oxide, refractories, coke, &c., are ground to powder, whilst the tougher metal particles remain whole. The metal, with the exception of the very fine particles, is separated from the dust by screening, and, after magnetic treatment, can be charged into the melting furnace.

Whilst clean foil can now be melted with quite reasonable yields, paper- or plastic-backed aluminium foil cannot be usefully charged into the furnace in that form. The charred residues of the paper would prevent the tiny droplets of alu-

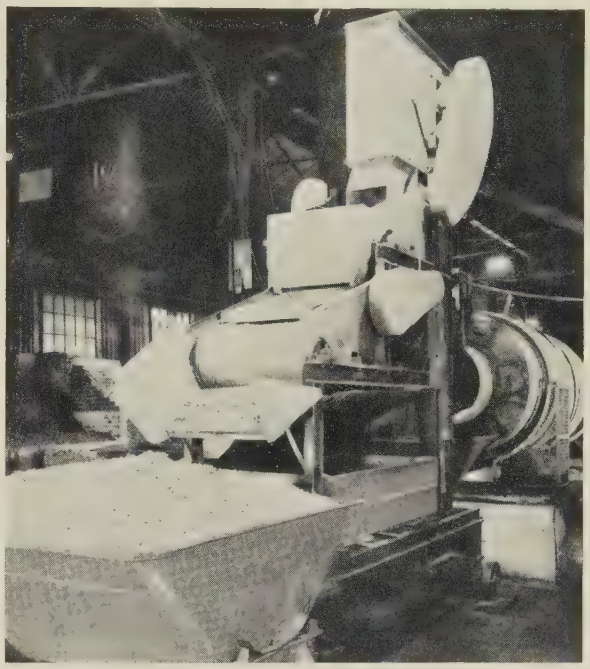
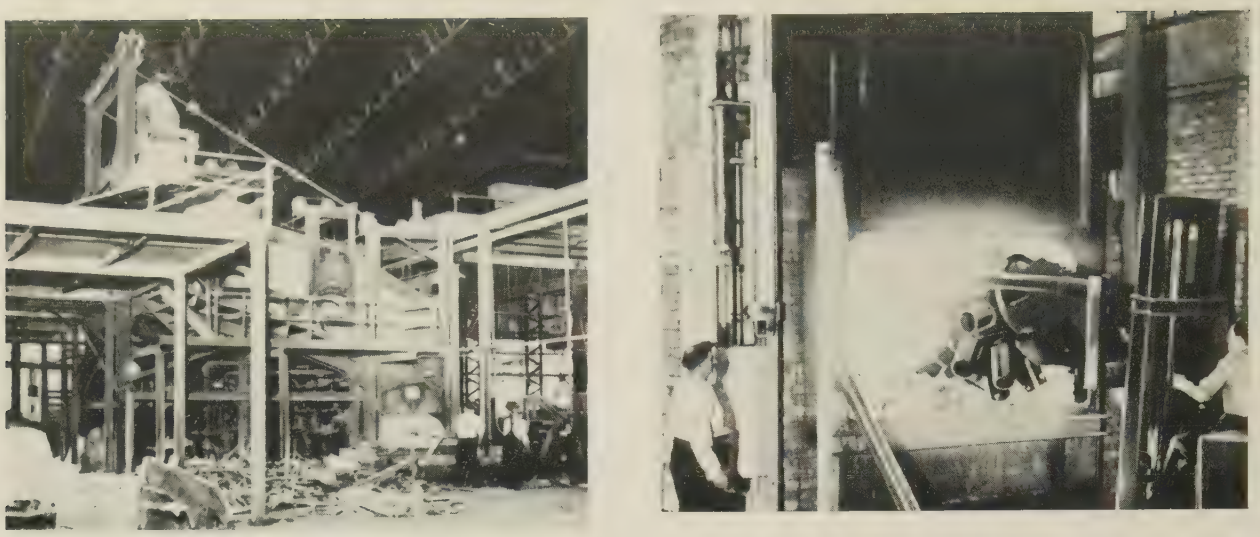


FIG. 2.—Apparatus for Treatment of Turnings.

minium produced from the aluminium foil from coalescing. The usual practice is to burn the paper, taking care not to raise the temperature so high as to melt the foil. This can be done in rotating drums, but needs careful operation. Similar treatment is required for some other material, e.g. insulated wire.

In the treatment of mixed structures of high-melting metals and aluminium, especially aircraft fuselages with their innumerable steel rivets, cables, and other non-aluminium parts, dismantling is generally out of the question. The method employed is described as liquation or more colloquially "sweating". The material is heated to a temperature above the melting point of aluminium but below that of the high-melting metals (steel, copper, &c.). This operation is carried out in a furnace with an inclined hearth.[10, 11] The liquid aluminium drains off this hearth and is collected in a forehearth or a heated crane-ladle for transfer to an alloying furnace. It can either be ingotted direct or after adjustment of composition to a given specification. (See Fig. 3).

Diagrams showing the general operational sequence in the preparation of aluminium scrap are given in Figs. 4 and 5.



(*a*) (*b*)

FIG. 3.—Illustrating Treatment of Mixed Structures for Recovery of Aluminium. (*a*) Side view showing charging platform (left). (*b*) Charging door, showing the charging of partly dismantled aero-engine by special truck.

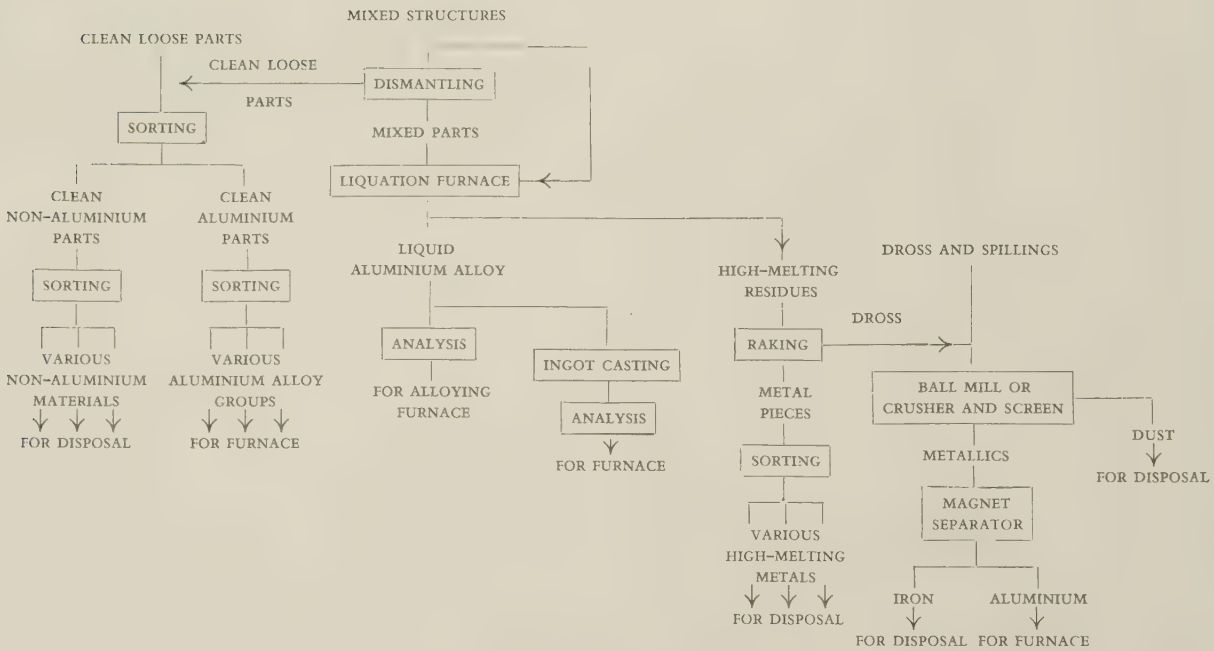


FIG. 4.—Operational Sequence for Processing of Aluminium Scrap.

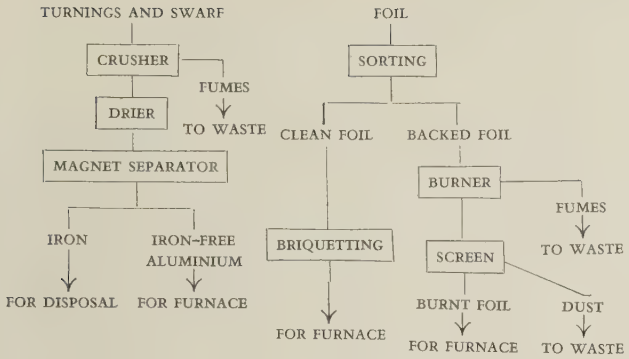


Fig. 5.—Operational Sequence for Processing of Aluminium Scrap.

Briquetting

Briquetting can have two purposes, one simply economic, i.e. saving of storage and furnace space and ease of handling, and the other, the reduction of air space between the metal particles with the aim of preventing oxidation. Only the first of these possible advantages has proved worth the cost in the case of aluminium scrap, and that only for light sheet and extrusion scrap, &c. For turnings there seems to be generally no economic justification for using this fairly expensive process.

Melting

There is not very much difference of technique between melting aluminium scrap down to the dimensions of normal sheet, and melting aluminium ingots. Only in so far as surface contamination by oil, paint, and dirt is concerned are special precautions necessary.

In the case of finely divided scrap, foil, turnings, borings, grindings, powder, and fine particles from dross, the important contamination is aluminium oxide, a highly refractory substance. This can be produced either by contact with furnace gases or with moisture, &c., contaminating these types of scrap. Dirt and lubricants can, of course, also leave refractory residues (silica, carbon) after the aluminium is molten.

It is this material which requires special treatment, because the aluminium oxide and refractory residues from lubricants have a tendency to prevent the coalescence of the small aluminium droplets formed initially. If this happens, a mixture of fluffy aluminium oxide and small aluminium droplets will accumulate on the top of the melt, and the droplets will burn to form oxide and nitride, producing a very high temperature. The consequence will be considerable oxidation loss, and the formation of sintered dense alumina particles which will sink in the liquid aluminium and may remain there as very hard inclusions. A thin oxide layer is, of course, present on dry and clean aluminium surfaces, and the problem of oxide inclusions and dross, but not of coalescence, is therefore also present in melting clean solid aluminium. It is only much intensified as the material becomes more finely divided and as the surface becomes more contaminated.

The three essential precautions in dealing with the oxide have been known in principle for a long time. They are:

(1) Agitation. This helps coalescence by mechanically breaking up the oxide skins separating the metal droplets.[12]

(2) Shortening the time of contact with air and surface contamination before particles reach the melting temperature. This is achieved by plunging the charged material into a heel of molten aluminium.[13]

(3) Excluding air and removing oxide from the metal surface by flux.[14, 15]

For the most part, all three methods are applied in combination. Of course the practical execution of these simple principles has been very much refined during the long period since they were first published.

Plunging or rabbling is carried out by charging the metal in portions so small that their addition does not at any time cool the liquid heel below the melting point, and working it in with steel rakes. The volatile part of the surface layers of paint or grease will then evaporate very quickly and with a minimum of oxidation of the metal surface. By repeated additions of small batches and continued heating, the metal bath is brought up to the final size. At the beginning of the melt the liquid heel can be formed by melting a small quantity of solid material or by melting fine particles in flux.

About the action of the flux, very little was positively known until recently. The problem was generally viewed in terms of solubility of alumina in the flux, and therefore it was considered necessary for cryolite, or at least fluorides, to be included in the flux, as cryolite is known to dissolve aluminium oxide, from its use in aluminium electrolysis. It is, however, a fact that—certainly at the temperature at which the slag is applied and is effective—no significant solubility of aluminium oxide in this flux occurs. Fluxes of potassium chloride and sodium chloride, which do not dissolve any appreciable amount of aluminium oxide, are practically as effective as fluoride casting fluxes.

In the author's laboratories it had long been realized that the mechanism of the removal of oxides from the liquid metal surface by the slag is based on surface tension. The liquid alkali chloride or fluoride is pushed by capillary forces between the liquid metal and the alumina skin, and lifts the latter off the metal surface, enveloping it in the process. Inside the body of liquid salt the liquid aluminium droplets no longer meet the resistance to coalescence that they experienced from the solid alumina skins.

The Fulmer Research Institute, at the instigation of International Alloys Ltd., have investigated this point [16] and have shown that this mechanism actually operates. It was further discovered that stirring assists in agglomeration of the metal particles. The alumina was found distributed in the liquid salt in very thin flakes, the shape of which confirmed that it had not been dissolved at any time.

The properties which characterize a good flux for aluminium melting are, therefore, its melting point, surface tension, and viscosity, rather than its power of dissolving aluminium oxide.*

As more and more metal is melted under the same batch of flux, the flux becomes more viscous and eventually crumbly, being unable to fulfil its functions any longer. The slag will then have to be discarded. Generally some aluminium pellets are still suspended in this slag, and it is often found economical to recover these by dissolving the soluble part of the flux (mostly sodium chloride) and elutriating the finely divided insolubles by a stream of water, leaving the metal pellets behind.

In Europe rotary furnaces of 1–8 tons' capacity, as illustrated in Fig. 6, using a comparatively thick cover of slag on the whole

* Cf. the work of E. F. Emley on fluxing of magnesium (*J. Inst. Metals*, 1948–49, **75**, 431).

bath, are the usual means of melting. In the U.S.A. reverberatory furnaces of up to 20 tons' capacity are preferred. In these furnaces a small part of the bath surface is partitioned off from the main hearth and made accessible outside the furnace proper, as shown in Fig. 7, and it is on this "well" that the charging of finely divided scrap and the flux treatment is carried out. This makes possible considerable savings in slag

Fig. 6.—European Type of Rotary Furnace for Melting Aluminium.

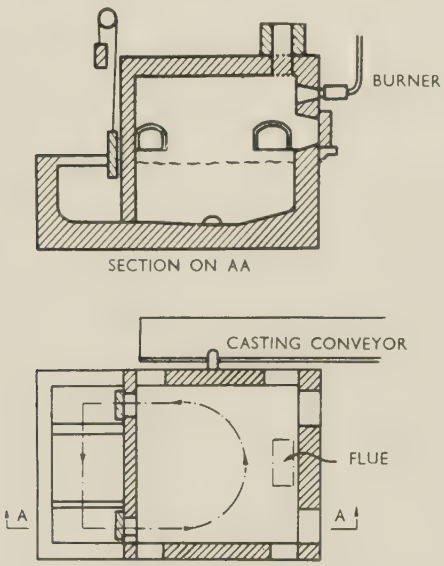


Fig. 7.—American Type of Open-Well Reverberatory Furnace for Melting Aluminium.

volume. The low-melting fluxes used in this furnace are, however, more expensive. From the handling point of view, as in all American designs, the furnace is very convenient. Discussion of the relative merits of these two types of furnace still continues between the specialists.

Casting

The casting of ingots is not an operation of great general interest, but production engineers have devoted a good deal of ingenuity to its mechanization. In Europe the old-established hand-ladle pouring method, which gives the cleanest ingots, is still widely employed. In the U.S.A. all the larger producers use conveyor-type casting machines.

Routine Refining Operations

Only two elements in the composition of the alloys produced from scrap are controlled by refining operations proper, magnesium and hydrogen.

Magnesium is present in many aluminium alloys in amounts between 0·1 and 1·5%; some less commonly used alloys contain up to 10%, but for others the content has to be very small, down to 0·10% or even lower, as this element influences the properties very strongly. In the bulk of the remelting alloy production a reduction of the magnesium content is required which cannot economically be attained by blending, as this would require large amounts of virgin ingot.

As magnesium is even more readily oxidizable than aluminium, it is possible to remove it on the traditional principle of metal refining, i.e. by selective oxidation. Slight agitation at suitably high temperatures in contact with air will reduce the magnesium content slowly. Much more rapid, but generally more expensive means, are chlorination and fluorination. The former can be effectively carried out by bubbling chlorine gas through the liquid alloy, or by plunging aluminium chloride, which evaporates and reacts by exchanging the aluminium it contains for magnesium. Fluorination is effected by treatment with slag containing aluminium fluoride, mostly diluted with sodium chloride or other inexpensive salts. The chlorine method is rather cumbersome, owing to the extensive installation and precautions required in handling large amounts of chlorine and disposing of the fumes produced by the reaction. Fluorination is quite convenient, but requires rather expensive materials. There is at present no clear preference for either of the three methods. Other proposed methods are mentioned in the next section.

Hydrogen is a component generally considered objectionable, as it produces gas porosity in aluminium castings. It is, however, present in small amounts in almost every melt, being introduced by reaction of aluminium with the moisture of the furnace gases. It can be removed from liquid aluminium by contact with reasonably dry air at low temperatures and in the presence of traces of flux, or by chlorination with chlorine gas or chlorine compounds, e.g. aluminium chloride or hexachlorethane, and also by treatment with nitrogen. All these methods are in use.

Range and Quality of Remelted Alloys

The quality of alloys produced from scrap, using up-to-date methods, is only a question of composition. At the beginning of the remelting industry 40 years ago, this was not always the case, and disappointments resulted. The increased knowledge of the effect of impurities and of melting, fluxing, and degassing, and last but not least, improved methods of analysis, have changed this completely.

In 1942 the B.N.F.M.R.A. carried out a rather elaborate investigation [17] comparing the properties of alloys of the same composition made from primary ingot or from metal remelted from finely divided scrap, turnings, and skimmings, in the laboratory or by reputable remelting firms. The investigation produced no indication of any difference in metallurgical quality between these two kinds of material, and this result is supported from other sources.[18–21] It has been pointed out by technical visitors to the U.S.A. that the producers of virgin ingot and the consumers of aluminium alloys alike have arrived at the same conclusion.[22] In this country, during World War II, very large quantities of scrap, especially turnings, had to be incorporated into the alloys for highly stressed aircraft parts, in order to maintain supplies. This was

done without relaxation in the requirements for properties of these alloys, and the performance of the parts made from this material seems to have given no indication of difference in quality.

Naturally the alloys with higher amounts of alloying components are easier to make from scrap than those with low percentages of additions. This explains why the larger part of the scrap goes into casting alloys, which generally have higher contents of alloying components. However, many high-strength wrought alloys have been and are being made to aircraft specifications incorporating considerable proportions of scrap. Some special alloys which require particularly low levels of impurities can, of course, be produced only from primary ingots.

Laboratory Activities

For the efficient processing of scrap into secondary alloys a considerable volume of laboratory control and co-operation is required. The work of the laboratory covers mainly the following points: composition of raw material as received and before charging, guidance in sorting operations and melting processes, analysis check on finished alloy, and metallographic inspection of ingots. Process and quality control on these lines is now maintained in up-to-date remelting works. For the composition control of large furnaces, several samples spread over the tapping period are examined to ensure homogeneity of the entire melt. In many cases checks on the concentration of vital components can be made while the metal is in the furnace. This is the rule for *all* elements in cases where direct-reading spectrographs are in operation.

Other Refining Processes for Aluminium

As mentioned above, the separation of pure aluminium from alloys, refining in the narrower sense, is an expensive operation. Almost all alloy components in aluminium alloys are chemically less active than aluminium. The traditional refining processes of selective oxidation (or selective combination) cannot be used in these cases. Only such elements as magnesium, calcium, and sodium can be and are being removed in the conventional way.

Certain more specific processes have, however, been devised in order to remove some or all of the nobler components, and some of these have been operated on a production scale. Others are more recent and still in the laboratory stage, but should be mentioned as potentially important.

Three-layer electrolysis is the oldest of the refining processes operated on a production scale.[23] It uses a special electrolytic cell with a top layer of liquid pure aluminium as anode. This floats on a layer of molten chloride–fluoride electrolyte, containing barium or strontium salts in order to give it a density between that of pure aluminium and of the liquid cathode alloy rich in heavy metals which forms the bottom layer below the electrolyte. The electrolytic action is to charge up Al^{+++} ions on the bottom of the electrolyte and discharge them at the bottom of the anode layer. The alloying components accumulate in the cathode as more and more alloy is added and the pure aluminium extracted. This eventually raises the melting point of the cathode alloy and from time to time some of it has to be discarded to keep the melting point within the right range. A part of the heavy metals can be segregated as aluminium compounds by liquation, and the rest of the alloy may be returned to the cycle. This process was operated in Germany during the war, but is uneconomic under peace-time conditions, as the energy consumption is nearly as high as with reduction of aluminium from alumina. It is still in use, according to its original purpose, for the preparation of very high-purity aluminium (99·9–99·998%) from material of normal purity.

A process based on the solubility of aluminium in mercury at high temperatures was in the pilot-plant stage in Germany towards the end of the war.[24–26] In it an aluminium alloy is leached with liquid mercury at 500°–600° C., and under pressures up to 20 atmospheres, when the mercury dissolves up to 30 wt.-% of aluminium. The amalgam is cooled to about 350° C., which causes primary crystals of aluminium to segregate. These are separated from the liquid by squeezing, and finally their mercury content is distilled off under hydrogen, leaving behind aluminium with a certain amount of the copper, tin, and other metals soluble in mercury.

This process only partly removes elements very soluble in mercury. It requires very elaborate apparatus, but is said to have worked well and reliably in the pilot plant. No information on actual industrial application is so far available. A similar but still more problematical process based on the solubility of aluminium in lead at 1000° C., has also been proposed.[27]

A further wartime large-scale experiment in Germany was the process worked out by A. Beck and his collaborators.[28] This is essentially a segregation by primary crystallization.

Segregation of this type by sedimenting the primary crystals had been in use for a long time, e.g. for separating iron from magnesium alloys. Separation by means of filtration on a bed of refractory grains and using air pressure for the purpose of forcing the liquid through the filter bed, had even been practised, in the case of aluminium–silicon alloys, before World War II. From what has been published since the war, it seems that this filtration process has been developed and is now reasonably practicable. Whilst not much is known about its industrial application since 1945, it is quite possible that it will eventually find a place in metallurgical practice.

The Beck process is a complex example of a separation of this kind. It makes use of the fact that certain alloy components, e.g. silicon, iron, and manganese, can be segregated very effectively as primary crystals (Si, Al_3Fe, Al_7Mn) from aluminium–magnesium alloys containing about 35% magnesium. In order to remove iron, silicon, and manganese from aluminium scrap, the magnesium content is raised to this order by adding magnesium alloy scrap containing, apart from magnesium, aluminium and some manganese (and occasionally zinc). The liquid alloy is then allowed to stand for a time at a suitably low temperature, filtered from the primary crystals, and finally the magnesium and zinc distilled off in a vacuum furnace. Some components, such as copper, which are soluble in aluminium–magnesium alloys at low temperatures remain or are only partly removed. Apart from the primary crystals, (probably of low value), pure aluminium containing copper, nickel, &c., and pure magnesium containing some zinc are recovered. The process has not been in operation since the war, and would probably prove uneconomical, first because of the cost of the vacuum-distillation operation, and secondly because there is no return from the large amounts of magnesium passing through the process along with the aluminium. A similar process using zinc instead of magnesium has been proposed.[29]

Zinc has been removed from aluminium alloys in this country on a pilot-plant scale by distilling it off in a vacuum.

A process termed catalytic distillation [30] has been suggested since the war, and opens up yet another approach to the problem of refining aluminium. It is based on the formation of an aluminium monohalide from liquid aluminium and aluminium halide vapour at high temperature and low pressure, e.g.:

$$AlCl_3 + 2Al \rightarrow 3AlCl$$

The monochloride is gaseous under these conditions. This reaction therefore permits the "evaporation" of aluminium from an alloy. The mixture of gases can be transferred to a "condenser", and by cooling (and/or compression), be decomposed:

$$3AlCl \rightarrow 2Al + AlCl_3$$

This process is now between the laboratory and the pilot-plant stage.

Both the mercury process and the catalytic-distillation process can, of course, be used to produce pure aluminium from aluminium–silicon–iron alloys, which in turn can be produced in the arc furnace direct from bauxite, &c., and carbon. This would be a way of making very pure virgin aluminium without intermediate purification of alumina and without electrolysis.

Acknowledgements

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THE ALUMINOTHERMIC PROCESS AND ITS VARIANTS

By T. BURCHELL *

THE principle by which aluminium in finely divided form can displace many metals from their oxides or other compounds, with formation of alumina or the corresponding aluminium compound, and the evolution of much heat, has been known for nearly a century. That it is today not only an economic method of smelting, but indeed the normal method of producing some of the metals and alloys which are of growing importance, is a surprise to many metallurgists who think of the burning of aluminium as an improper and wasteful proceeding.

Some who are trying to conserve metals would at first look askance at a method which completely uses a metal now accepted as one of the major non-ferrous group. They would, however, then reflect that to exchange a small amount of one of the commoner metals for a greater amount of a more expensive less-common metal, now needed as an addition element in alloy metallurgy, is not such bad economics after all.

Further, it would be fair to consider aluminium as a solid form of stored energy, largely derived from electrical energy generated in countries where the latter is cheap. Since much of the aluminium used in the process is secondary, this is even cheaper as a source of the energy needed, in comparison with the cost of electricity here. Thus, from the dollar angle, although ostensibly each ton of secondary aluminium consumed nationally will only be replaced, if required, by virgin metal at dollar cost, all this aluminium has already been used at least once, as primary metal; and any new import of virgin metal nationally needed will permit a further fresh use in ways for which much of the secondary would not be suitable, because the latter has often been so far alloyed that its potential uses have become restricted. This means that the corresponding virgin metal would in any case be imported, and this secondary aluminium would probably find its way into the deoxidation of steel, as being the only other application left open for it. This also is a destructive use.

Technical Considerations

Technical reasons why the use of aluminium as a reducing agent is advantageous include the following:

(1) The large amount of oxygen with which it combines, in smelting, allows most metals to be reduced by a small proportion of aluminium per unit.

(2) The heat evolved is sufficient to produce fluid metal and slag, with good separation, and the metal is thus obtained in massive form rather than in flakes or powder. This allows it to be alloyed subsequently in large-scale melts of other metals with greater ease.

(3) The process is very flexible, and allows change at short notice from one smelting operation to another.

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(4) The fused alumina slag produced is useful as a refractory and in other ways.

(5) Metals reduced in this way have exceedingly low carbon contents, and to produce results approaching these by electric-furnace reduction is very costly.

Thermodynamics

The thermodynamics of the process are illustrated by the simple case of the reduction of iron, and depend on free-energy relationships:

$$Fe_2O_3 + 2\,Al \equiv Al_2O_3 + 2\,Fe + 197{,}000\ \text{cal.}$$
$$(-\ 195{,}600\ \text{cal.}) \qquad (+\ 392{,}600\ \text{cal.})$$

Here, the heat of formation of alumina so far exceeds that of ferric oxide that the balance is sufficient to melt metal and slag, and produce a temperature of 2700° C., taking into account the sensible heat in melted alumina and pure iron, and latent heat of fusion and specific heat also. Broadly, any such reduction can be carried out where the balance of heat is sufficient to achieve similar fluid metal and slag, and not greatly in excess of this. In the latter event, a violent reaction takes place which may be dangerous, owing to constituents assuming the vapour phase in large proportions, with explosive effects.

For this reason, great care must be exercised in the practice of the process, particularly with peroxides and other "loose" compounds, including oxides very readily reduced by carbon, such as those of copper, tin, lead, and the other metals near that end of the electrochemical series. Dr. Kondic in his paper has stressed the importance of thermodynamics and in particular free-energy data, and a very good example is provided by this process, which demands their consideration at all times to avoid error and risk. Without the use of all such data as have gradually become available, the process could never have been developed as it was over a wide field of metal smelting, embracing the main production of carbon-free manganese, chromium, boron, titanium, zirconium, vanadium, niobium, tantalum, molybdenum, and tungsten, and their alloys with iron, copper, aluminium, nickel or cobalt, or with each other.

History

It is said that Davy predicted the usefulness of the metal in the earth known as alumina as a means of reducing other oxides, when considering his isolation of the alkali metals, but certainly St.-Claire Deville and Wöhler showed that this was the case, following the former's early production of aluminium by the sodium-reduction process. The idea remained a scientific curiosity until the eighteen-nineties, when Hall and Héroult perfected the electric-furnace reduction of aluminium, and the metal became cheap enough to allow commercial application of the principle.

A crude ferro-vanadium produced then in Britain was swiftly followed by work in a City Road, London, laboratory by Hugh Pickard and Claude Vautin, which by 1898 had achieved enough success to attract the attention of Dr. Hans Goldschmidt, of Essen. The latter acquired the process and at once began to develop it with great skill and application, at Essen, so that in a few years the production of manganese and chromium was amounting to many tons annually, and the method of welding by "Thermit", utilizing the reaction with iron oxide given as the example, was being used in many countries on tram-tracks and in repairs to steel castings. Goldschmidt's main technical contribution was the method of initiating the reaction by means of a very small amount of barium peroxide and aluminium powder which could be lit with a match.

Development

Before 1914 there were subsidiaries of the Goldschmidt firm in several countries, including Britain, and here the management of the concern passed to the Nobel Group, to whom it was subsequently transferred. In 1929, the business was acquired by Murex, Ltd., of Rainham, Essex, who are carrying on a large range of smelting and welding operations at the present time. There are now several other users of the process in the country, and the metal and alloy produced here by its aid totals over 15,000 tons annually. The exothermic oxidation of finely divided aluminium is also utilized in welding and in anti-piping compounds and ingot-head feeders, ladle-heating additions, hairdressing compositions, foodstuff heating, the jointing of copper cable and of the magnesium used in cathodic protection of pipe-lines, and the production of small special alloy castings by the aid of the lost-wax process.

One of the anxieties of all firms and workers normally concerned in the use of this process is the safeguarding which must be a cardinal principle if the technique is to retain its reputation. Owing to the ease with which small and simple reactions can be carried out without expensive plant, there is a danger of inexperienced workers being misled into extensions of their operations, which have sometimes proved injurious to life and limb; and it is a pity that such an elegant metallurgical technique should be in any way threatened, in the confidence it enjoys, by careless or uninformed applications of the principle. In the welding application great care is exercised in training those firms who carry out their own repair-welding by its aid.

There has been in recent years, as tramways have tended to decline, an increase in the use of the process to weld the joints in the long overhead crane-tracks which are a feature of many modern steel mills; the wear near each joint is thus greatly minimized, and strain on the crane carriages lessened in turn. Among the plant welded in this way is the extremely long track in the steel mill at Margam. The copper-bonding of electrical cable by the process is developing, with quantities of up to 12,000 joints for some of the installations in which it is used overseas.

The chromium used in high-temperature alloys for gas turbines is largely made by the aluminothermic process; and also the ferro-niobium used in special steels for rotor discs in these engines. Manganese metal for aluminium hardening, and for deoxidation of brass and bronze, cupro-nickel, and nickel-base alloys, is also largely made in this way. Titanium alloys for aluminium hardening, and the stabilizing of stainless steel, form another application; while ferro-vanadium for high-speed steel and other alloys is produced by the same means.

The work done by the secondary-aluminium melting industry, with its improvement in segregation of scrap and quality of recovered metal, and the larger tonnages which have been available since its operators entered the field seriously, have greatly assisted the development of the aluminothermic process in recent years. Dr. Scheuer in his paper has described this secondary aluminium and aluminium alloy industry and its part in the task of making the best use of metals. The aluminothermic process furnishes another valuable contribution, for not only does it make good use of aluminium, but it also reclaims waste metals in the form of scale and oxidized products, arising from operations such as wire-drawing of copper and steel. Sometimes alloy steel containing tungsten, from scale arising from other fabricating processes, is also reclaimed in this way.

THE RECOVERY OF COPPER AND ZINC FROM LIQUID AND GASEOUS EFFLUENTS

By S. HANDS,* M.Sc., A.R.I.C.

Introduction

THE treatment of copper and its alloys by pickling in sulphuric acid after annealing in oxidizing atmospheres results in a considerable annual loss of copper and zinc, chiefly as water-soluble sulphates formed by the action of acid on the oxide scale. This loss occurs for the most part as "drag-out" of pickling liquor when metal is transferred from the acid to the wash-water, while a quantity is also lost when pickle boshes are periodically discharged. Recovery of copper at least has been attempted in the past, but with the coming into operation of the Rivers (Prevention of Pollution) Act of 1951, which empowers River Boards to fix the quality of effluents discharged into rivers, it is now obligatory both to neutralize acid and to reduce considerably the concentration of toxic metal. Coupled with the need to comply with the requirements of this Act, the high prices of copper and zinc have in recent years stimulated interest in ways and means of accomplishing this purification in the most economical manner.

Many tons of zinc are also lost as fume during the melting of brass, and it is important that this fact should be given prominence in any general scheme for recovering metals from effluents.

Displacement of Copper from Effluents by either Iron or Aluminium

It is a well-established fact that a metal may be displaced from solution by a second metal which has a lower position in the electropotential series. Thus, metals such as iron, aluminium, and zinc will all displace copper, and recovery processes based on this chemical exchange have been in operation for many years. Although the underlying principle is straightforward, recent experiments have established that with a continuous flow of effluent the copper content can only be reduced to approximately 20 p.p.m., the maximum flow rate being about 0·25 gal./hr. and the minimum time of contact with steel turnings about 2 hr. Consequently, this method is applicable only to the actual pickle liquor, and it is doubtful whether any great saving of metal would result from the treatment of wash-water effluent, where the copper concentration is rarely greater than 50 p.p.m., and in any event the volumes to be dealt with are usually so large—in some instances as much as a million gallons a day—that a maximum flow rate of 0·25 gal./hr. would be quite impracticable.

Precipitation may be carried out in the pickle bosh, after analysis to determine the correct amount of iron to be added, or if working space is limited the liquor may be discharged by gravity feed into an underground pit to avoid the installation of pumping equipment and elaborate precautions against corrosion. The copper content of the exhausted solution is usually about 0·01%. Since the labour and maintenance costs of such a process must inevitably be low, the value of copper recovered may be as much as £200/ton at present-day prices. This, of course, does not include the cost of rendering the final effluent suitable for discharge into river water, but since this cost would have to be borne in any event it has been justifiably omitted.

Because copper is precipitated in the above process in a finely divided form, the possibility of using this material for powder-metallurgical operations has recently been investigated. It was established that the main impurities were copper oxide, iron, and alloying elements such as chromium, manganese, and nickel. Precipitation by aluminium in the presence of a small amount of sodium chloride (0·02%), followed by purification by washing with acidified copper sulphate solution, however, resulted in a relatively pure material (99% copper and 1% oxygen). After reduction in a cracked-ammonia atmosphere, disintegration, and sieving, a satisfactory powder was obtained.

Electrolytic Recovery from Pickle-Bosh Liquors

(a) *Copper from Copper and Brass Pickle Liquors*

Industrial experience indicates that both copper and brass pickle liquors cease to function satisfactorily when the copper content is more than 80 g./l. If, however, copper build-up can be prevented, then with occasional additions of sulphuric acid the life of a solution may be considerably extended, thus preventing the formation of an undesirable effluent. This may, in fact, be accomplished by electrolysis, *in situ*, with lead anodes and copper cathodes. It is not proposed to describe here the construction and functioning of an electrolytic unit, since there are many electrochemical engineering firms who specialize in this equipment. However, it may be mentioned that production experience with copper pickle liquor has established that the greatest efficiency is obtained when recovery is effected from a solution having a copper concentration between 9 and 12 g./l., the potential difference across the electrodes being 2·5 V. and the current density 12 amp./ft.². Under these conditions about 1 lb. of copper is obtained for the expenditure of 2 kWh., equivalent to a power efficiency of 72% at the bosh, and the acid consumption is reduced from 21 to 13 lb./ton of copper pickled. A detailed account of the working of a unit consisting of four boshes, handling 250 tons of copper a week over a period of twelve months, is given in Table I. Laboratory trials have established that, within certain limits, the presence of zinc in solution has no significant effect on copper deposition, so that the foregoing remarks may also be applied to brass pickle liquors.

TABLE I.—*Recovery of Copper from Pickle Liquors*

Bosh No.	Operating Time, hr.	Power Consumed, kWh.	Carboys of Acid Consumed	Copper Recovered		Efficiency, kWh./lb.
				tons	cwt.	
1	5640	16,920	25	3	15	1·99
2	5895	18,310	18	4	12	1·75
3	6390	21,920	11	4	4	2·30
4	6380	22,160	15	4	6	2·29
Total	24,305	79,310	69	16	17	Average 2·08

Estimated consumption of sulphuric acid without recovery plant in operation . . 8–10 carboys/week
Quantity of metal handled . . . . 230 tons copper/week

Removal of copper by electrodeposition has found favour of late for a number of reasons, the chief of which are that the

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plant once in operation requires little attention, the process is continuous, and in many instances the electrical equipment can be so arranged as not to interfere with pickling operations, while the regeneration of sulphuric acid may, in the saving on this item alone, more than balance operational costs. It must be remembered, however, that complete copper recovery cannot be expected, since some metal must inevitably be lost as drag-out.

(b) *Zinc from Brass Pickle Liquors*

If brass pickle liquor is maintained in a working condition by continued electrolytic removal of copper, zinc will build-up in solution, and eventually the liquor will have to be discharged. At this stage the liquor may contain about 10 g./l. of copper and as much as 100 g./l. of zinc. It might be mentioned here that low current densities, about 5 amp./ft.^{2} are essential for satisfactory deposition of copper from brass pickle liquors, otherwise loose spongy cathode deposits are obtained. Zinc recovery from the discarded liquor would not be a simple matter, since zinc cannot be deposited electrolytically in the presence of copper or small amounts of other more electronegative metals. Removal of these impurities would therefore be necessary, and the most practicable method of accomplishing this would be by chemical displacement with zinc, even though acid neutralization would automatically occur. From the resulting pure zinc sulphate solution it would then be possible to recover by electrolysis at least 75% of the zinc, an equivalent of sulphuric acid being generated at the same time. Complete metal recovery would not be economical, however, since in electrolytes with both low-zinc and high-acid concentrations re-solution of the cathode deposit occurs and poor current efficiencies are obtained. Finally, part of the spent electrolyte could be returned to the pickle bosh as acid make-up liquor and the remainder passed to the neutralizing pits for discharge as effluent.

Recovery of Copper and Zinc from Pickle Rinse-Water by Ion-Exchange Resins

In the previous sections attention has been devoted to possible methods of recovering copper and zinc from pickle bosh-liquors. It is now proposed to deal with the more difficult problem of wash-water effluents, which vary appreciably in composition, depending, for instance, on the shape of the product, method of rinse, flow rate, age, and metal-to-acid ratio of the mother pickle liquor. A typical effluent sample may contain copper 20, zinc 15, and sulphuric acid 50 p.p.m. Their very dilute nature makes them difficult to deal with, and it was not until the advent of ion-exchange resins that any hope of successful treatment materialized. Briefly, ion-exchange resins are complex organic materials with a natural affinity for removing metal ions from dilute solutions and may be obtained in either the hydrogen or sodium form. Thus, when a dilute solution containing copper, zinc, and calcium is passed through a resin bed the following reaction occurs (R refers to the resin network):

$$R\begin{Bmatrix}H\\Na\end{Bmatrix} + \begin{matrix}Cu^{++}\\Zn^{++}\\Ca^{++}\end{matrix} + SO_4^{--} \longrightarrow R\begin{Bmatrix}Cu\\Zn\\Ca\end{Bmatrix} + \begin{matrix}H_2SO_4\\Na_2SO_4\end{matrix}$$

The reactions proceed according to the rules of chemical equivalency until the resin bed is ultimately exhausted. The regeneration step, which is the reverse of the above equation, is usually carried out with either 20% sulphuric acid or strong sodium chloride solution according to which form of resin is employed, and under favourable conditions may result in a solution containing as much as 5% copper and zinc. In effect, then, a many-hundredfold concentration of metal ions has been accomplished with a minimum of cost. The regenerant may then be electrolysed to recover the copper, but not the zinc, and in practice returned to the pickle bosh as acid make-up. A schematic drawing of a system employing ion-exchange resin for concentration of copper [1] is depicted in Fig. 1. A controlling factor in the successful operation of such a unit, however, is the total hardness (calcium and magnesium) content of the rinse-water, which may be as much as 100 p.p.m., since these metals would also be extracted along with the non-ferrous metals, and because calcium sulphate is only slighly soluble in water, its removal from the resin bed would

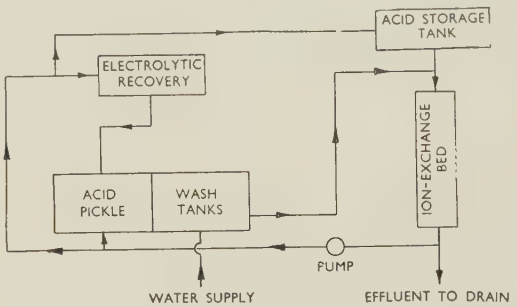

Fig. 1.—Schematic Representation of Ion-Exchange System for Concentration of Copper in Pickle Wash-Waters.[1]

present a major difficulty. In such a process the use of softened water for pickling and washing would therefore be essential. Finally, in dealing with brass pickle rinse-waters zinc build-up would also have to be considered, and it is doubtful whether the effect of this factor could be determined other than by pilot-plant-scale evaluation of the process.

Metal Recovery Following Lime Neutralization of Effluents

If, in accordance with the Rivers (Prevention of Pollution) Act, 1951, effluents containing spent pickle, pickle wash-waters, and waste soluble oils resulting from fabrication processes are purified by lime neutralization, then all the metal present may be precipitated and collected as hydroxide sludge. A recent examination of these sludges has indicated that they are broadly of two kinds: (1) the oily scum usually removed before neutralization, which is formed when acid-bearing effluents and soap suds are mixed; and (2) the neutralizing sludge proper, which consists of calcium sulphate, excess lime, together with the hydroxides of copper, zinc, and any other heavy metals present in the effluent. At present useful recovery is not made from either of these sludges.

Analysis of a typical oily scum has established that it may contain up to 1% copper and 0·5% zinc. Quantities of the order of 50 gal./week, equivalent to about 400 lb./annum of metal, are removed from the separating pits, and it is obvious, therefore, that only if the oily waste could be used as a fuel would it be worthwhile considering this material. A survey of several neutralizing pits showed that the neutralizing sludge proper contained copper 4, zinc 6, and calcium 30%, which corresponds to many tons of wasted metal during the course of a year. Unfortunately, the presence of such large proportions of calcium compounds would make the sludge difficult to process, and at the moment the only possible method of recovering copper and zinc would be by extraction with sulphuric acid followed by electrolysis. It is extremely doubtful, however, whether this could be justified economically

and, in any event, if electrolytic recovery is to be pursued, then the most suitable juncture is before and not after neutralization.

Recovery of Zinc from Zinc Oxide Fume

The amount of zinc oxide in the fume from an Ajax–Wyatt furnace engaged on melting brass has recently been determined over a period of several weeks under typical factory conditions. It was established that the flue dusts contained between 60 and 80% zinc oxide (with small amounts of copper and lead oxides and some carbonaceous matter arising from mould grease), representing at least 1 ton of zinc from every thousand tons of brass cast. If the fume can be conveniently removed, either by cyclones or by bag filters, it should be possible, either by dissolution in sulphuric acid followed by electrolysis or even by direct reduction with carbon, to recover almost all the zinc. Further, it might be possible to operate the electrolytic process in conjunction with the scheme oulined earlier for the treatment of waste brass pickle liquors, since suitable acid leaching solutions would be readily available. Consequently, of all the recovery processes so far discussed, recovery of zinc from furnace fumes would appear most worthy of further consideration.

Acknowledgements

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THE ECONOMICAL USE OF METALS

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(Communication from The British Non-Ferrous Metals Research Association)

THE first recommendation of the report of the Metals Economy Advisory Committee of the Ministry of Supply, issued 11 September 1952, reads as follows:

> "We recommend that: (1) the Government should emphasize through its many contacts with industry the continuing need for making the most economical use of metal supplies by the adoption of the latest and best techniques, in order to overcome present shortages and avoid waste, and as a precaution against any recurrence of the world shortage of metals or a shortage in the United Kingdom arising from balance-of-payment difficulties."

Although what follows is in no sense a Government-inspired statement, we make the recommendation our justification for presenting this paper. The key words are: "by the adoption of the latest and best techniques" and "to avoid waste". We propose to outline briefly some techniques which might be so classified, but which still await general adoption, and some we feel might come under the heading of wasteful practices, in the hope of stimulating discussion and revealing where more research or development work is needed.

Specifications

We do not propose to say much about the supply of raw materials to the industry, since this is covered by the earlier papers. One point which does, however, call for comment is that of specifications, particularly in relation to impurities. When metal supplies are tight, or when prices are high, it is, of course, essential to make use of as much scrap material as possible, and it is very necessary that specifications should be drawn up with this in view. Wherever possible the tolerance allowed for impurities should be as wide as possible, consistent with the material performing its function satisfactorily. This is not always so at present. Often specification-drafting committees feel they must take a conservative view, usually because of the dearth of reliable information about the effects of impurities. This sometimes means that alloys have to be made from virgin metals instead of scrap, or that certain supplies of scrap cannot be used because of the danger of exceeding the impurity level. These remarks apply especially to the many specifications which place an arbitrary limit of, say, 1% on the total impurities. It sometimes happens that quite large quantities of a particular element may be present without ill effects—it may even enhance some properties of the alloy—but the impurity limit is then exceeded.

The B.N.F.M.R.A. has carried out several investigations in the past to determine the effects of impurities, and in its current research programme work is being undertaken to enable a safe limit to be determined for the zinc content of aluminium–silicon–copper alloys of the D.T.D.424 type (B.S. 1490: LM4). The effects of tin and antimony in hot-stamping brass are also being examined with the possibility in mind of drawing up a more realistic specification for this widely used alloy. Doubtless there is scope for much more work along these lines, and perhaps we shall hear in the discussion today of specifications where a more realistic view of impurity levels is needed.

Zinc-Containing Residues

We should like to touch on one other point in connection with raw materials, and that is the use made of some of the lowest grades of metal residues. This applies mainly to the brass trade. The practice of recovering skimmings from Ajax–Wyatt furnaces has made available considerable quantities of low-grade residues consisting of zinc oxide, some copper oxide, and metal dust. One plant reclaiming metallics from ashes and similar residues alone, produces these oxides in quantities equal to about 1% of the total consumption of zinc in this country. When it is appreciated that the difference between adequate supplies of a metal and a shortage is usually only a matter of a few per cent., such quantities are of considerable significance. Firms producing ingots for the copper alloy foundry industry also collect quantities of oxides of this type from the fumes of the refining furnaces. Sometimes these are sufficiently pure to be attractive to the pigment manufacturers, but often contamination makes them unsuitable for this purpose. As indicated by Mr. Hands, there seems to be

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very little outlet for such waste products in this country at present, and consideration might well be given to setting up a plant for the recovery of zinc or other metals from these oxide residues, possibly by an electrolytic process along the lines of the Tainton process for electrogalvanizing wire. The cost of the raw material should be very low indeed, so that there should be ample scope for the development of a workable, economic process.

Losses in the Sand Foundry

We now pass from the question of raw materials to manufacturing techniques. Melting losses in the wrought nonferrous metals industry are already mostly of a low order, and it is probably true that there is small room for improvement. On the sand-casting side of the industry losses are higher, and cause a considerable wastage. Metal losses when melting gun-metals in crucibles are often of the order of 5% or more. When it is realized that the output of copper alloy castings in this country is of the order of 100,000 tons/annum, and a 5% loss means 5000 tons of metal, these figures take on a new significance. These losses could surely be reduced by using charcoal or blanketing fluxes to prevent oxidation and by better handling methods such as lip-axis-pouring crucible furnaces, which reduce the chance of spilling metal during pouring into ladles, and overhead conveyors for carrying ladles round the foundry. When melting yellow brasses, especially in reverberatory furnaces, metal losses can be very high. In one such case, experiments proved that the melting losses could be reduced from 10–12% down to 3–4% by using a flux cover. The annual saving of metal which would result from the adoption of this procedure in the firm in question is between 150 and 200 tons. Of course, not all of this metal would be irrevocably lost. Some would be recovered from residues, but it would be very much down-graded in the process, and the cycle of loss, collection, and recovery costs money.

It is impossible to neglect the production of scrap as one contributory cause of metal wastage. The work of the B.N.F.M.R.A. has contributed materially to the reduction of scrap in some of its members' bronze foundries. For instance, the use of nitrogen degassing of gun-metals to ensure consistently gas-free metal, coupled with the utilization of metal/mould reaction, has led to an overall reduction of rejects of about 3% in one valve foundry and a reduction of rejects from an average of 10% to about 2% on certain classes of work. Another foundry making specialized copper castings reports a reduction in scrap of from 5% to less than 1% following the adoption of routine degassing and careful control of pouring temperatures. In another instance, modifications to the gating technique lowered considerably the number of castings rejected because of inclusions, while modifications to the sand in the same foundry reduced metal penetration so considerably that the fettling shop, instead of being a bottleneck, was able to cut down its labour force. This must also have brought about a marked saving in metal, since fettling losses may easily amount to 3% of the weight of the casting.

Of considerable importance in reducing the weight of metal melted to make a given casting, and hence indirectly lessening metal losses, is the work being carried out by the B.N.F.M.R.A. and others on the use of insulating sleeves and exothermic compounds for reducing the size of feeder heads. So far, at least in the Association's work, attention has been concentrated on the bronze sand-casting side of the industry, where there is great scope for increasing the casting-weight : metal-melted ratio, which may sometimes be only 50% on account of the large feeders needed to render the casting sound. Surrounding the feeders with insulating sleeves made from foamed plaster, or with exothermic compounds, enables their size to be reduced to about one-third of the volume needed when the feeders are moulded in sand, and the yield is correspondingly increased. Similar methods are being investigated to reduce the size of pipe in billet casting and so raise the yield. Incidentally, the use of these improved methods of feeding would also eliminate the need for topping-up billets with fresh metal, which is a time-wasting process.

Losses in the Wrought Industry

In the manufacture of wrought metals, however, by far the largest wastage of metal must surely occur through scaling during heat-treatment and hot working and in the removal of this scale by pickling. This applies very largely to the wrought copper and brass industry. The oxide scale on hot-rolled copper wire rod amounts to about 0·2% by weight. The tonnage of wire rod produced annually in this country is of the order of 200,000 tons. Hence, 400 tons of scale is produced per annum. Much of this is not lost, since many firms hot rolling copper rod operate electrolytic-recovery plants to reclaim the copper from the pickles used to clean the rods, but nevertheless the wastage is probably quite high. Some surface oxidation is inevitably produced during hot rolling, but much must occur in preheating the wire-bars. Could not this be avoided by using neutral atmospheres such as steam or even by coating the wire-bars with a protective paint or flux? (This latter idea is being explored for the steel industry by the British Iron and Steel Research Association.) Losses caused by scaling become still heavier when dealing with sheet or strip, where the surface-area : weight ratio is much higher. Bright-annealing or clean-annealing atmospheres could be used much more generally to reduce these losses and incidentally to dispense with or reduce the need for pickling. Although it may not always be easy or practicable to get a true bright anneal without a great deal of trouble, clean annealing leaving only a thin oxide bloom on the metal can often be achieved more easily; the result is lower metal losses and less pickling required.

Where pickling has to be carried out, it is encouraging to see that small copper-recovery plants are now being made by some of the electrochemical engineering firms and are being installed alongside pickling tanks in a number of works. The B.N.F.M.R.A. lay great stress on the importance of marketing equipment of this sort. It is too much to expect the small works to build it themselves. The saving of copper and acid which will result from the more extensive use of these recovery plants should be considerable. Usually, it is found that the value of the acid saved pays for the current consumed, and the copper recovered will generally pay for the equipment within 18 months or 2 years. We suspect that when copper recovery is practised it will usually be found that pickling is also more efficient, since the solution can be maintained at a more or less constant composition instead of fluctuating in activity as fresh acid is added or the pickle becomes exhausted.

In rolling the more "difficult" alloys, edge-cracking can often lead to rejection of an appreciable width of the rolled strip, which has to be trimmed off and reprocessed. Recent work of the British Iron and Steel Research Association has shown that this cracking can be eliminated or very much reduced by keeping the edge of the material square during rolling. It would be interesting to know whether this conclusion can be exploited industrially, either by using guide rolls to roll the edge square as the material enters the work rolls, or by choosing suitable conditions of lubrication or roll surface which will reduce the tendency for the edges of the material to bulge out.

Is it not also possible to reduce wastage at the ends of coils of strip by handling it in longer lengths? In the smaller works restrictions on the size of slab cast may present an obstacle, but this could be overcome by welding lengths together after breaking down. The Wrought Non-Ferrous Metals Productivity Team report mentions the use of argon-arc welding for this purpose in the U.S.A.

Might it not be possible, also, to improve the yield in the extrusion process by some means of lubrication which would improve the pattern of flow and so reduce the discard. What we have in mind is some adaptation of the Séjournet process, which uses glass as a lubricant, that could be applied to copper alloys or light alloys.

The User's Part

So much for the manufacturer. What can the user do to avoid waste of metals? The user is, or ought to be, interested in obtaining his material at the lowest possible price without sacrifice of quality. He must be governed largely by the functions the material has to perform. Hence it is of primary importance that he chooses the right alloy for the job and that he selects the best method of manufacturing the part. In this latter connection we have very much in mind the use of die-castings, hot stampings, extruded sections, or even of powder metallurgy as a means to producing the finished job with the minimum of machining.

By comparison with the U.S.A., it seems that in this country manufacturers are still reluctant to advertise their achievements and we feel that this is restricting progress. For example, when someone finds he can reduce manufacturing costs and save metal by, say, substituting a hot stamping for a component machined from bar, let him tell the other man about it. Let other designers benefit from your experience. Articles on subjects like this in the technical Press, particularly the engineering Press, would do much to popularize new methods of manufacture and new materials, which usually result in metal economies.

The choice of the right alloy must sometimes be a difficult one for the design engineer who must to a large extent bear the brunt of a breakdown in service. He has a number of factors to consider—strength, method of manufacture, the possibility of corrosion in service, the type of finish required, number of parts to be made, and so on. Often the information about the properties of the available materials is very meagre, and it is not to be wondered at that he often plays safe and selects an alloy which he knows has given satisfaction in a similar application in the past. This is all very well for the designer, but it often leads to the reverse of economy in the use of metals. For example, it could lead to requests for material of non-standard composition when an everyday standard product would do equally well. Or again, it may mean the use of an expensive high-grade material for an application where a lower-grade alloy would be just as good. An example is the use of phosphor bronze or Admiralty gun-metal castings for steam valves for which 86 : 7 : 5 : 2 leaded gun-metal made from secondary materials might be perfectly suitable.

It must be admitted, however, that the designer is not always as well supplied with information as he could hope to be. The Development Associations are doing much through their various booklets to keep the engineering industry up to date and, of course, many metal manufacturers themselves have reached a high standard in trade literature about their own products. But much still remains to be done in this field, both in the provision of reliable data and in putting the information across to the engineers.

In the first field, the B.N.F.M.R.A. and industrial research laboratories have a special part to play. It is relatively simple to obtain ordinary tensile properties for materials, but for many engineering problems such information is of limited value, and it is on the results of long-term creep and fatigue tests that the engineer must base his calculations. The Association has in its laboratories some 70 creep units, as well as a number of fatigue machines, suitable for operation at room temperature or elevated temperatures up to 750° C., and in the past few years a considerable body of information has been made available on the long-term mechanical properties of various light alloys and copper and copper alloys. Much of this information is essential for new engineering projects where the designer has no precedent to work on. Nevertheless, it is often just as important to establish the properties of some of the older types of alloys. For example, currently we are examining the creep properties of the leaded gun-metals at high temperatures, to see just what stresses they can withstand and how far they can replace more expensive alloys. Possibly more work of this kind is needed before engineers have the information that will enable them to replace one alloy by another with complete confidence.

One should not only consider the possibility of using a cheaper alloy as a replacement for a more expensive one; sometimes economy in the use of metals may be achieved by the reverse process. The use of silver-bearing copper, with its greater resistance to softening at high temperatures, instead of ordinary high-conductivity copper allows higher operating temperatures in alternators and motors and so makes possible a saving of conductor material. Another example is hollow conductors, doubtless more expensive to produce, which have been used successfully in hydrogen-cooled alternators. The heat generated by the current in the conductors is dissipated by a stream of hydrogen passing through them, and this has enabled the weight of copper in the machine to be reduced by about 40%. One wonders to what extent high-strength alloys such as silicon bronze or aluminium bronze could replace phosphorus-deoxidized copper, particularly in corrosion-resistant applications. These alloys are about half as strong again as copper, and they have good ductility, although they work-harden rapidly. It should be possible to reduce gauges considerably without sacrificing strength, and it would be interesting to see how the economics would work out. It is realized, of course, that there is often a limit to the reduction of section thicknesses because of the need for rigidity, although the incorporation of strengthening ribs or corrugations in the design can sometimes help.

One should also bear in mind the possibilities of clad material, which can to some extent combine the virtues of its two constituents. Aluminium-clad Duralumin is well known, but might there not also be a big field for copper-clad aluminium, or copper-clad steel?

Protection against Corrosion

Finally, a word must be said about the protection of metals against corrosion, which probably results in by far the biggest wastage of metal. There is still an urgent need for propaganda on this subject. Often the use of a material in an unsuitable environment can do great harm to its reputation. With the increasing use of aluminium alloys for all kinds of purposes, it is more necessary than ever to make sure that the right alloy is used in corrosion-resistant applications, that the pitfalls of "mixed systems" resulting in contact corrosion are avoided, and that if the material is to be painted or electroplated it is properly prepared so that the coating does not flake off in a short time.

Many non-ferrous metals find considerable application in providing corrosion-resistant and decorative coatings on steel and decorative coatings on other non-ferrous metals. There has been much publicity in recent years regarding the serious economic loss to the community represented by the corrosion of iron and steel, and the steel industry itself, through its co-operative research agencies, has taken a leading part in the evaluation of corrosion-resisting finishes. We are all familiar with the work of Dr. J. C. Hudson and his collaborators in this connection. In addition to much evaluation of the performance of paint coatings, the corrosion-resistance of zinc coatings has been studied, and it is of interest to know that at the present moment B.S.I.R.A. is doing work on the development of processes for the hot-dip aluminium coating of steel. The recent serious shortage of zinc focused attention on economy in the use of this metal in the galvanizing process, and the B.N.F.M.R.A. undertook development work in an industrial plant, subsequently used as a demonstration centre for the rest of the industry, to find out how far zinc could be saved by the application of principles arising from the Association's previous research on the galvanizing process.

It was found, for example, that a saving of 15% of the total zinc consumption could be achieved in that particular works by reducing coating weight, and by restricting immersion times and withdrawal rates to the practical minimum. By some rearrangement of the work this was achieved without lessening the overall production rate, and furthermore the effective corrosion protection afforded by the coatings was not reduced. In fact, the heavier coatings previously applied were non-uniform and zinc was being wasted in fairly large blobs which afforded no corrosion protection. A further 4% saving was achieved by introducing a simple method of recovering the entrained metallic zinc from zinc ashes. Similarly, in the electroplating industry the introduction of drag-out tanks has been advocated as one means of economizing in the consumption of scarce nickel compounds used in plating.

This latter field is one where there is much scope for collaboration between the designer and the producer of the article, to see that, on the one hand, crevices and other features favouring corrosion are avoided and on the other that the product is one which can be handled with maximum efficiency by the galvanizer, electroplater, metal sprayer, &c., who is called upon to provide the final corrosion-resistant protective coating.

DISCUSSION

Professor A. J. Murphy * said that agreement would be general with Mr. Stubbs' statement of the present position. The main problem in the non-ferrous industry today was probably not the shortage of materials but the shortage of customers. An interesting point was that no-one appeared to regard this as anything but a very temporary phase. Whereas fifteen years ago doubt would have been expressed as to the possibility of restoring the volume of trade to its previous level, this was now regarded only as a matter of time, and recovery was expected at no very distant date. He thought, therefore, that some primary producers were inclined to be too conservative in reading the signs and to lend too little weight to the rapidly accelerating volume of demand arising from the increase in world population and the widespread demand for a higher standard of living.

He was impressed by the necessity for this country in particular to exploit to the utmost the recovery of useful metal from secondaries. As trade increased, we should be less and less able to devote manual labour to the recovery of scrap, and a good deal of thought and research should be devoted to the problems of handling secondary metals in the mass. Electrolytic recovery afforded one such means, and further developments should be possible in separation by differential-gravity flotation and ion-exchange methods. This applied particularly to the secondary copper industry, where a great deal of scrap metal was still recovered by the simplest manual operations which it would be difficult or impossible to mechanize.

Presumably the metallurgist would be accorded an increasing say in the use of metals for completely destructive purposes. He had never ceased to be shocked at the proportion of lead—close to 10% of the metal mined each year—irretrievably lost in tetraethyl lead.

Mr. L. C. Batchelor, † with reference to the paper by Mr. Stubbs, enquired what volume of copper refining was carried out in this country. Mr. Miller had mentioned the effect of certain elements—notably nickel—in decreasing the conductivity of copper. There was in this country a large production of fire-refined H.C. copper from certain grades of blister bar, and he would like to know to what extent the impurities mentioned affected the conductivity. Special measures could be taken to eliminate some of the impurities, but not the nickel.

The recovery of copper and zinc from pickling solutions, &c., as described in Mr. Hands' paper, had been operated by some of the larger firms with success for a number of years. It had been suggested that some firms did not adopt this method because of plant-design difficulties, but this did not present any serious obstacle. The only requirement was a suitable generator or rectifier, with the necessary bus bars and anodes and cathodes, which could be installed actually in the pickling boshes. In a development of this method with which he had been concerned twenty-five years ago the lead anodes and copper cathodes had been suspended in the boshes. For a firm engaged in pickling copper wire and strip it presented a useful means of recovering copper and saving acid.

So far as zinc-containing residues were concerned, these could be used for the recovery of zinc oxide and were of some value, even at the present price of zinc.

Dr. E. G. West ‡ expressed his firm belief, arising from contact with industry on the development side, that a most effective means of securing metal economy would be a greater use of standards and a greater measure of standardization. He would add to this simplification, through the use of a smaller number of standard materials. This would assist the refiner and also the fabricator and founder, by making possible longer runs on a few alloys. In the case of aluminium alloys—and no doubt with other metals—the change from one type of alloy to another, with the consequent cleansing of furnaces, constituted a considerable hindrance to economic operation.

* Professor of Industrial Metallurgy, Birmingham University.
† Imperial Chemical Industries, Ltd., Metals Division, Birmingham.
‡ Technical Director, Aluminium Development Association, London.

The use of standards had to be correlated with information passed on to the metal user, and the metallurgist should make his voice heard to a much greater extent than at present. Too often his recommendations were overruled on price considerations, and by insisting on material possessing the properties required for the work in question, the metallurgist could make a valuable contribution to metal economy.

The choice of the best material led naturally to design factors, which in turn offered many opportunities of metal saving. The production of complex assemblies by welding together simple castings, or mixed assemblies of castings with wrought materials, was a case in point. This use of welding was becoming better known, and by avoiding the casting of difficult shapes, entailing greater metal losses, larger runners and risers, &c., it provided many opportunities for economy, especially with the new processes now available.

The increasing shortage of fuel of every kind in this country lent further urgency to the reduction of the amount of metal melted and to finding the most efficient forms of heating. It was interesting, for example, to compare the fuel consumption, expressed in B.Th.U. and in kWh. to produce virgin aluminium and refined scrap. From this point of view it might be attractive to use more virgin metal, since it was not made in this country and therefore employed "fuel" available elsewhere.

Finally, Dr. West said that members of the Institute, particularly those concerned with the use of non-ferrous metals, could perform a real service by bringing forward problems for investigation. Facilities for carrying out research were plentiful, but the definition of problems and their ranking in order of importance was too often left to a few people who might be fairly remote from the metallurgist in the user's works.

Mr. B. Walters * thought that Mr. Hall and Mr. Mantle had been a little unkind to the zinc industry in some of their remarks. The industry traditionally absorbed a large proportion of the residual material from galvanizing; some materials, such as fumes, were more difficult to treat. The zinc smelter was alive to the necessity of recovering zinc wherever possible.

Mr. Stubbs, in connection with Mr. Hall's observation that manufacturers could make better use of metals by redesigning "without sacrificing quality", expressed the opinion that designers should also endeavour to maintain a certain standard of quality. Many articles—including the modern motor car—combined some parts whose quality was too poor, with others which far excelled the required standard.

Mr. Hands said that his firm produced about 600 tons/annum of zinc oxide from brass-furnace skimmings. At present the material was sold, he thought for zinc oxide pigment, but he would like to ask Mr. Walters whether there was any practical process, other than electrolysis, for converting it back to zinc.

Mr. Walters replied that in his view the pigment industry provided the most suitable home for the residual in question.

Mr. Miller referred to the figure quoted by Mr. Hands in his paper of about 5000 kWh./ton involved in the recovery of copper from pickling solution. His own firm operated a recovery plant consuming less than 3000 kWh./ton of copper recovered, and even this was considered unsatisfactory in view of the fact that primary metal producers—using solution methods on their ore supplies and then recovering copper by electrodeposition with inert anodes—operated at about 2000 kWh. He wondered therefore whether Mr. Hands was concerned with a copper + zinc sulphate solution, and not with a straight copper sulphate pickling solution. He thought that in brass pickling liquors zinc was naturally present in much greater quantities than copper, and that there was a limit to which electrolysis could be employed in the case of mixed pickling solutions because of the increase of zinc. Perhaps Mr. Hands would enlarge on that point.

Mr. E. C. Mantle, also commenting on Mr. Hands' contribution, expressed surprise at the low copper contents (9–12 g./l.) recommended for maximum recovery of copper from copper sulphate solution. In the few experiments which he had carried out, he had found that recovery of copper was not at all easy below about 2% wt./vol. (20 g./l.); the deposits were poorer in quality and gassing tended to occur. He would have thought that in that region efficiency was beginning to decline and that it would be better to work with a more concentrated solution. The 25 g./l. of sulphuric acid mentioned also seemed to him rather a low concentration for efficient pickling; he would have expected a much higher figure in most pickling solutions.

With regard to Mr. Miller's remarks Mr. Mantle said that it must be borne in mind that drag-out always tended to keep down the concentration of salts in pickling solutions to a certain level, and it was difficult to get above, say, 10% of zinc or copper in any such solution because the drag-out tended to produce an equilibrium value; often indeed the concentration did not rise as high as that.

Mr. Miller replied that in the working conditions involved, the copper content probably averaged 6–8 oz./gal.; the figure preferred was 4 oz./gal., but the concentration could fluctuate up to as much as 10 oz., depending on the throughput of work. Possibly the concentration of copper in the solution influenced the amount of current needed.

Dr. R. H. Roberts said that the question had been raised of the cost of recovery of zinc from zinc oxide by electrodeposition and an electricity consumption of 5000 kWh./ton had been quoted. This agreed closely with the 0·6 kW./year (or just over 5000 kWh./ton of zinc produced) published as the total power requirements (including power used for crushing, grinding, &c.) of an Australian zinc company.

In England 5000 kWh. would cost about £25, which explained why electrolytic refining could make little headway in this country against the traditional distillation methods, in spite of the difficulties involved in treating zinc residues, &c., by such methods.

Mr. Hands, replying to Mr. Mantle, said that the figures quoted had been arrived at by his firm's research department, operating a recovery unit under factory conditions. It was difficult to lay down specific limits, bearing in mind that three variables were involved—percentage copper, percentage sulphuric acid, and current density. Variation in any of these might affect efficiency.

With regard to the efficiency of the electrolytic process, it was necessary to avoid confusion between the power input into the generator and the power taken out of the generator.

* The National Smelting Co., Ltd., Avonmouth.

The current efficiency of about 74% which he had quoted was the bath efficiency, i.e. the efficiency of the electroplating tank, but there was a loss of power in the generator and also some voltage drop if the connections were unsatisfactory. Kilowatt-hours, unfortunately, were based on voltage and amperage, so that while amperage efficiency should be specified, voltage must also be taken into account.

He thought that the figure for power efficiency worked out at about 50%. This was rather a low figure, particularly in comparison with copper refining, but it must be remembered that the plants were not operated by technically qualified personnel, but usually by the man who was doing the pickling, with some supervision by the shop foreman. Efficiencies of the order of 95–100% were unobtainable, and would in any case only result in a relatively small financial gain. To work at 50% efficiency probably added £10–20/ton to the cost, a small sum in comparison with the £200/ton value of the copper recovered.

His company operated a recovery unit at Smethwick pickling brass tubes, and he thought that the zinc build-up was of the order of 5 oz./gal. (30 g./l.). At that point the liquor was discarded, not because the copper could not be extracted, but because the high concentration of zinc sulphate in the pickle liquor stained the tubes. That was the limiting factor. It was, however, possible that some system of washing the tubes could be devised, thus enabling the process to be continued beyond that point. In another factory producing brass wire, a figure of about 5 oz./gal. had been laid down, and the pickle liquor was discarded when it reached that concentration.

Mr. Miller, replying to Mr. Batchelor's question about the effect of composition on the conductivity of fire-refined copper, said that fire-refined H.C. copper produced from imported Rhodesian blister, had a conductivity of the order of 100·7%. The elements present, which could be regarded as a "hall-mark" of the type of copper, were silver (1–1½ oz./ton), selenium 0·01, bismuth 0·001, and nickel 0·005%. The silver, selenium, and bismuth occurred in the ore bodies; the nickel was introduced into the matte at the smelting stage and originated from the pulverized coal used. 0·005% nickel represented a fair average, and this depressed the conductivity by 0·4%; 0·01% nickel would depress the conductivity by about 0·8%. The highest recorded value of the conductivity yet attained was 102·2–102·3%, on copper specially refined in small quantities for investigational work. The conductivity of commercial electrolytic copper varied from 100·0 to about 101·7%. The latter was attained only at two or three refineries in the world, where large quantities of ore bodies of stable composition were available and where excellent maintenance of electrolytes was practised. Most of the American refineries, he thought, did not produce copper with a conductivity higher than 101·0%, partly owing to the more mixed materials used and partly owing to deliberate addition of copper scrap in the final melting operation. Data indicated that 5–10% of scrap was used in the production of high-class H.C. electrolytic copper in U.S. refineries.

Mr. Batchelor had also asked what steps were taken to remove impurities in the fire-refining process. The lime–soda ash process to remove arsenic and antimony was the only one practised to any extent. In Michigan, treating ores which sometimes contained arsenic up to 0·5%, it was in regular use, and by repetition it was possible to bring the arsenic content down to 0·002%. Arsenic did not, however, in general present a problem in the case of Rhodesian coppers, and with the grade of copper coming forward for treatment in this country he did not think that it was worthwhile adopting this process.

Mr. Hall said that he and his co-author were not unappreciative of the very great difficulties involved in operating zinc-smelting plants or of the complexity of the process. However, if this country was moving forward into a position where every ounce of imported material had to be looked at very carefully it meant that a new situation had to be faced and that efforts to develop methods for recovery of zinc from low-grade residues, hitherto regarded as uneconomic, might be worthy of consideration. He knew that the industry was devoting attention to this aspect and that there was no easy answer to the problem.

Professor Murphy said that Mr. Stubbs had referred to the situation that might eventually be reached if the volume of trade became stabilized. In the case of a metal with an eventual recovery factor of 70% and a process scrap total of 20% (figures which were not far off the mark for aluminium or copper), the final balance would be attained with an intake of only 25% virgin metal, the return of old scrap constituting 50–60% of the metal consumed in manufacture. These were broadly the lines of operation towards which metal economics would tend.

Mr. Stubbs expressed interest in Professor Murphy's observation that less virgin metal than scrap might eventually be used. In nearly all European countries the consumption of the majority of non-ferrous metals, except aluminium, had not risen much over the last twenty years, perhaps because they were being used more efficiently and in less bulk than previously. Unless there was a steady rise in consumption, the proportion of scrap available for use would become larger and larger in proportion to the quantity of virgin metal consumed. Professor Murphy had suggested that the primary producers were being a little conservative in not expanding their output more, but his own opinion was that the demand during the post-war years had been exceptional, since it included stock-piling and rearmament, neither of which could be expected to continue. He doubted whether metals would have been in short supply but for these exceptional demands, and so producers could not be blamed for proceeding cautiously with plans for new production. Nevertheless, shortages had led to fresh sources of supply being sought, and hardly a day passed without news of discoveries in Canada and elsewhere, many of which would perhaps now not be needed for another ten or twenty years.

In reply to Mr. Batchelor's question, he thought that the output of refinery copper from imported blister in this country amounted to 120,000–140,000 tons/year.

Professor Murphy said that what he had intended to suggest was not that the primary producers should increase their capacity now, but that they should give due consideration to the probability of future demand, which as far as he could see would continue to expand for at least another generation.

Mr. Stubbs said that he would have entirely agreed with Professor Murphy's view a year ago; today he was not so sure.

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NEWS OF LOCAL SECTIONS AND ASSOCIATED SOCIETIES

Visits by the President and Secretary

The President, who has already paid visits, during the present Session, to the Scottish Local Section, Sheffield Local Section, and the Leeds Metallurgical Society, will pay official visits to other Local Sections and Associated Societies during the 1953–54 Session as follows, accompanied by the Secretary:

North East Metallurgical Society, Friday, 11 December 1953.
South Wales Local Section, Tuesday, 12 January 1954.
Manchester Metallurgical Society, Wednesday, 20 January 1954.
Birmingham Local Section, Thursday, 21 January 1954.
London Local Section, Thursday, 4 February 1954 (provisional).
Oxford Local Section, Tuesday, 2 March 1954.
Liverpool Metallurgical Society, Thursday, 11 March 1954.

South Wales Local Section

At the first meeting of the session, held at University College, Swansea, on 6 October, Mr. T. E. COUND lectured on:

The Heat-Treatment and Hot Working of the Nimonic Series of Alloys

In his introduction he indicated the nature of the arduous operating conditions awaiting high-temperature materials to be used in aircraft gas-turbine jet-propulsion units. Then followed the chemical analyses and short-time tensile strengths up to 1000° C. of some of the nickel–chromium–titanium–aluminium alloys in the Nimonic series; the location of their application in the unit was described. An account of the effect of heat-treatment on structure and creep-resistance was given, showing the effect of rate of cooling from solution-treatment temperature and stressing the importance of a metallurgically stable structure. The relationship between the temperature of solution-treatment and creep-resistance was indicated.

The aspects of hot working discussed included the effect of increasing alloy complexity on hot workability; the necessity for careful control at all stages from raw material to final inspection was shown. The rate of heating before hot working and some of the difficulties associated with cooling from the hot-working temperature were discussed. Finally, the production of rod by extrusion and the principles of blade production were described.

OTHER NEWS

The Platinum Metals Exhibition

The importance and widespread use of the platinum metals in many industries were demonstrated at an exhibition, held by the Institution of Metallurgists in London last October, to commemorate the announcement in 1803 by William Hyde Wollaston of his discovery of the metal palladium, an announcement which took the unusual form of a handbill offering the metal for sale in a Soho shop.

Although it may be popularly thought that the platinum metals are used mainly for jewellery and luxury articles, in fact more than 75% of the total production of these metals goes to industrial applications, the main uses resulting from their high melting points and great resistance to corrosion and oxidation.

One section of the exhibition consisted of an interesting collection of items connected with Wollaston and his discoveries and with the early history of the platinum metals. Pages from Wollaston's notebooks show the first reference to palladium by name against a date in 1803.

Other noteworthy exhibits were a design for a palladium cup presented to Charles X of France in 1824 by Robert Breant, chief assayer to the Paris Mint, and an inventory, in Faraday's hand, made in 1834 of the platinum and palladium given to the Royal Society by Wollaston. Of earlier historical interest were photographs of jewellery made by American Indians before the time of Columbus.

The remainder of the exhibition was devoted to exhibits designed to show the uses of the different metals and alloys of the platinum group in industry. These included electrical contacts, sparking-plug electrodes, catalysts in the chemical industry, spinning jets for the rayon industry, tips for fountain-pen nibs, and many others.

Some fine examples of the arts of the jewellery craftsman were included in the exhibition, and perhaps the most noteworthy were a very fine rose bowl in palladium–rhodium presented to H.R.H. the Princess Margaret by the Institution of Metallurgists on the occasion of the opening of the exhibition "Metals in the Service of Mankind" in 1950, and a richly ornamented casket from Canterbury Cathedral of platinum set with diamonds.

The jewellery exhibits included a palladium tiara produced by the investment-casting process, the rubber moulds, wax replicas, and sections as cast being shown.

Supply of Pure Metals

In 1947 the Chemistry Research Board of the D.S.I.R. set up a Pure Metals Committee to investigate the position with regard to the supply of metals in a high degree of purity and to initiate any necessary work which would increase the availability or purity of such materials. The Committee has purchased, through the Director of the C.R.L., stocks of metals of a high standard of purity, either in the form of specially prepared batches or as a safeguard against the unforeseen disappearance of a particularly good grade of material from commercial production. The intention is that these stocks shall be available for urgent research purposes, at cost plus a small handling charge, and it therefore seems desirable to make known to those interested what metals can be obtained.

In the following list purity, per cent., indicates the content of uncombined metals in the specimens. In most cases complete chemical analyses can be supplied, and the quantities available are on at least the pound scale.

	Purity, %		Purity, %
Aluminium	99·99	Nickel	99·96+
Antimony	99·92	Niobium	99·7
Bismuth	99·97	Potassium	99·99+
Cadmium	99·99+	Rhenium	99·99
Cobalt	99·95	Silicon	99·93
Copper	99·99+	Sodium	99·99+
Gallium	99·98+	Tantalum	99·9 +
Germanium	99·99+	Thallium	99·9 +
Indium	99·993	Tin	99·99+
Iron	99·96	Titanium	99·92
Lead	99·99+	Vanadium	99·7
Lithium	99·98	Zinc	99·99+
Manganese	99·8 *	Zirconium (+ hafnium)	99·75

* Remainder oxygen.

Enquiries in connection with this stock should be addressed to the Secretary, Pure Metals Committee, Metallurgy Division, National Physical Laboratory, Teddington, Middlesex.

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By Maurice Cook, D.Sc., Ph.D., F.I.M. and C. L. M. Cowley, B.Sc., A.I.M. (*Imperial Chemical Industries, Ltd., Metals Division*)

The Control of Quality in Melting and Casting Copper and High-Conductivity Copper-Base Alloys.
By J. Sykes, F.I.M. (*Enfield Copper Refining Co., Ltd.*)

The Control of Quality in the Casting of Zinc and Zinc Alloy Rolling Slabs and Extrusion Billets.
By C. W. Roberts, B.Sc., A.I.M. and B. Walters, M.A. (*Imperial Smelting Corporation, Ltd.*)

The Control of Quality in the Melting and Casting of Aluminium Alloys for Working.
By R. T. Staples and H. J. Hurst (*T. I. Aluminium, Ltd.*)

The Control of Quality in Melting and Casting Magnesium Alloys for Hot Working.
By R. G. Wilkinson, B.Sc. and S. B. Hirst, B.Sc.Tech. (*Magnesium Elektron, Ltd.*)

General Discussion and Indexes.

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STUDENTS' ESSAY PRIZES

Those eligible are reminded that entries for the two Students' Essay Prizes of twenty guineas each, awarded by the Council, must be submitted by 1 January, 1954.

Regulations governing the awards are given in detail in the September 1953 issue of the *Bulletin* (p.1).

Entries should be addressed to:

The Secretary
THE INSTITUTE OF METALS
4 Grosvenor Gardens · London, S.W.1

EQUIPMENT FOR THE

THERMAL TREATMENT

OF NON-FERROUS METALS AND ALLOYS

Cloth. 4to. 1952. *Pp.* 104, *with* 14 *plates and numerous figures in the text. Price* 15*s. or* $2.50, *post free.* (*Members, one copy each at* 7*s.* 6*d. or* $1.50, *post free.*)

CONTENTS: Electric Furnaces for the Thermal Treatment of Non-Ferrous Metals and Alloys; Gas Equipment for the Thermal Treatment of Non-Ferrous Metals and Alloys; Batch and Continuous Annealing of Copper and Copper Alloys; Bright Annealing of Nickel and its Alloys; Batch Thermal Treatment of Light Alloys; Flash Annealing of Light Alloys; Continuous Heat-Treatment of Aluminium Alloys of the Duralumin Type.

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Corrosion and Its Prevention

The Committee of the Corrosion Group of the Society of Chemical Industry, having found that there is a large demand for special lectures on corrosion and its prevention, has decided to constitute a Panel to deal with the educational side of its work. The Panel that has been formed includes representatives from the Group Committee, from universities and technical colleges, from industry, and from the Ministry of Education. Its present constitution is as follows: Dr. W. H. J. Vernon (Chairman), Mr. T. H. Turner (Vice-Chairman), Mr. S. C. Britton (Hon. Secretary), Mr. W. E. Ballard, Mr. R. W. Blount, Mr. L. W. Derry, Dr. H. B. Footner, Dr. J. E. Garside, Dr. T. P. Hoar, Dr. J. W. Jenkin, Dr. S. J. Kennett, and Dr. W. S. Patterson. The terms of reference are: "To promote and encourage instruction in knowledge of metallic corrosion and its prevention; for example, by special courses of lectures or by the introduction of corrosion study into the curricula of universities and technical colleges."

There appear to be three main needs to be met: (1) Training of full-time corrosion specialists, which must be carried out predominantly in post-graduate courses at a few establishments where facilities exist. (2) Provision of an outline of knowledge of corrosion and its prevention to engineers and others who, although not primarily concerned with corrosion, must frequently take its effects into account. (3) Provision of advanced instruction in some particular field for those who wish to have up-to-date knowledge.

The Panel has already made considerable progress in seeking to meet the second and third of these needs by giving help in arranging special courses of evening lectures. A further step is now being planned, namely a residential course of instruction on the fundamental aspects of corrosion and its prevention, to be held at the Battersea Polytechnic from 19 to 23 July 1954. The introduction of instruction on corrosion science into normal curricula is very desirable, and it is hoped that lecturers from educational establishments will take advantage of the residential course to gain knowledge of the subject and to discuss how such instruction can be fitted into existing courses. Details of this project will be available shortly. The Panel will be very glad to assist in the promotion of lecture courses, and any teacher who is interested should write to the Hon. Secretary of the Corrosion Group Education Panel, c/o the Society of Chemical Industry, 56 Victoria Street, S.W.1.

Conference on Defects in Crystalline Solids

The H. H. Wills Physical Laboratory of the University of Bristol, in co-operation with the International Union of Pure and Applied Physics (particularly its Commission for the Physics of the Solid State) and with The Institute of Physics, is organizing a conference on "Defects in Crystalline Solids" to be held from 13 to 17 July 1954, in Bristol. Although not excluding other subjects in the field, the organizers propose to give particular attention to defects such as dissolved atoms, vacancies, and *F*-centres; to microwave resonance methods of investigating their properties; and to the way in which they react with dislocations. Thus dislocations will be discussed in their chemical aspects, as influencing diffusion and precipitation in the solid state, rather than in relation to plastic flow.

It is hoped that a number of authors from overseas will personally present their papers, and with this in mind the Conference has been arranged to follow immediately after the General Assembly of the International Union of Pure and Applied Physics. Board and lodging will be provided in Wills Hall, a student hall of residence, on special terms, or at hotels. The Conference is open to any scientist interested in this field, subject to the limitations of seating accommodation.

Further particulars may be obtained from the Secretary, H. H. Wills Physical Laboratory, Royal Fort, Bristol 8, or from the Secretary, The Institute of Physics, 47 Belgrave Square, London, S.W.1.

Those wishing to attend the Conference are asked to apply to the former, marking the envelope "1954 Conference", stating whether they wish to be accommodated at Wills Hall or at an hotel and for what nights accommodation is required.

Leverhulme Research Fellowships, 1954

Application is invited for Fellowships and Grants in aid of research. The Fellowships and Grants are intended for senior workers who are prevented by routine duties or pressure of other work from carrying out research. They are limited to British-born subjects normally resident in the United Kingdom. In exceptional circumstances the Trustees may waive the condition as to residence.

The Trustees are also prepared to consider applications from groups of workers engaged upon co-operative programmes of research, particularly from those engaged upon long-distance programmes.

The duration of the awards will not normally extend over more than two years or less than three months, and the amount will depend on the nature of the research and the circumstances of the applicant.

Forms of application may be obtained from the Secretary, Miss M. Branney, Leverhulme Research Fellowships, 3/5 Salisbury Square, London, E.C.4 (Telephone: City 1910).

Applications must be received on or before 31 December 1953. Awards will be announced in May, and will date from 1 September 1954.

Fifth International Spectroscopy Colloquium

It has now been announced that this Colloquium will be held in 1954 in Austria, not in Belgium as at first suggested. The Spectrochemical and Colorimetric Group of the Verein Österreichischer Chemiker is acting as host, and has chosen the dates from 30 August to 6 September, so as to precede the Institute of Metals Autumn meeting in Zürich. Further details will be announced later, but the Colloquium will be held in the Salzkammergut district of Austria.

Institution of Metallurgists : Change of Address

The offices of the Institution of Metallurgists have been moved from 4 Grosvenor Gardens, London, S.W.1, to 28 Victoria Street, London, S.W.1 (Tel.: ABBey 4922/3).

DIARY

The Institute

1954

6 January. Informal Discussion on "Lubricants for Metal-Working Operations in the Non-Ferrous Metal Industries". (Birmingham University, Edgbaston, Birmingham 15, at 10.30 a.m.)

Local Sections and Associated Societies

1953

14 December. Scottish Local Section. "Corrosion, Particularly under Marine Conditions", by Dr. P. T. Gilbert. (39 Elmbank Crescent, Glasgow, C.2, at 6.30 p.m.)

30 December. Birmingham Local Section. "Metals in Telecommunications", by C. E. Richards. (James Watt Memorial Institute, Great Charles Street, Birmingham 3, at 6.30 p.m.)

1954

5 January. Oxford Local Section. "Industrial Methods of Electroplating", by Dr. G. E. Gardam. (Oak Room, The Cadena Café, Cornmarket Street, Oxford, at 7.0 p.m.)

6 January. Manchester Metallurgical Society. "Recent Development in Magnetic Materials", by A. E. De Barr. (Lecture Room, The Central Library, Manchester, at 6.30 p.m.)

7 January. Leeds Metallurgical Society. "Applications of Spheroidal Graphite Cast Iron", by Dr. A. B. Everest. (Chemistry Department, The University, Leeds 2, at 7.15 p.m.)

7 January. London Local Section. "The Rogerstone Strip Mill", by F. King. (4 Grosvenor Gardens, London, S.W.1, at 6.30 p.m.)

12 January. North East Metallurgical Society. Metallurgical Brains Trust. (Cleveland Scientific and Technical Institution, Middlesbrough, at 7.15 p.m.)

12 January. South Wales Local Section. "Continuous Casting", by J. Crowther. (University College, Metallurgy Department, Singleton Park, Swansea, at 6.45 p.m.)

14 January. Liverpool Metallurgical Society. Discussion on "The Corrosion and Preservation of Metals". (Liverpool Engineering Society, The Temple, Dale Street, Liverpool, at 7.0 p.m.)

Other Societies

1953

4 December. Royal Institution. "Dislocation, Fracture, and Fatigue", by Professor N. F. Mott. (The Royal Institution, 21 Albemarle Street, London, W.1, at 9.0 p.m.)

8 December. Institute of British Foundrymen, Slough Section. "Sands", by A. P. Lovat. (Lecture Theatre, High Duty Alloys, Ltd., Slough, at 7.30 p.m.)

10 December. Institute of Welding, Slough Section. "Gas Welding", by F. Clark. (The Community Centre, Farnham Road, Slough, Bucks., at 7.30 p.m.)

10 December. Institute of Welding, South London Branch. "Hydrogen *versus* Welding", by Dr. C. L. M. Cottrell. (2 Savoy Hill, London, W.C.2, at 6.30 p.m.)

15 December. Institute of British Foundrymen, East Anglian Section. "Any Questions?" (Central Hall, Public Library, Ipswich, at 7.30 p.m.)

15 December. Sheffield Metallurgical Society. "Analysis of Magnesium Alloys", by A. Mayer. (B.I.S.R.A., Hoyle Street, Sheffield, at 7.0 p.m.)

16 December. Institute of Welding, North London Branch. "The Application of the Self-Adjusting Arc" (with B.W.R.A. Film), by P. T. Houldcroft. (Manson House, Portland Place, London, W.1, at 7.30 p.m.)

17 December. Institution of Mining and Metallurgy. General Meeting. (Rooms of the Geological Society, Burlington House, Piccadilly, London, W.1, at 5.0 p.m.)

1954

4 January. East Midlands Metallurgical Society. "The Contribution of Research to the Technology of Cast Iron", by Dr. R. V. Riley. (Nottingham and District Technical College, Shakespeare Street, Nottingham, at 7.30 p.m.)

4 January. Institute of British Foundrymen, Sheffield and District Branch. "Examples of Loam Moulding as Applied to Production of Pump Casings and Impellers", by E. Clipson. (Sheffield College of Commerce and Technology, Department of Engineering, Pond Street, Sheffield 1, at 7.30 p.m.)

11 January. Institution of Production Engineers, Sheffield Section. "Extrusion of Metals", by J. T. Lewis. (The Grand Hotel, Sheffield, at 6.30 p.m.)

APPOINTMENTS VACANT

CHEMIST. A vacancy for a chemist in the Physical Metallurgy Section of a fundamental research laboratory. Good degree in chemistry and experience in experimental work required. Familiarity with vacuum apparatus, reactive materials, or transitional metals an advantage. Apply in writing to Personnel Officer, Associated Electrical Industries, Ltd., Research Laboratory, Aldermaston Court, Aldermaston, Nr. Reading, Berks.

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH requires Scientific Officer at National Physical Laboratory, Teddington, for research on analytical techniques in metallurgy. Experience of micro-analysis an advantage. 1st or 2nd class honours degree in inorganic or physical chemistry. Age—not below 21; post unestablished with possibilities of establishment through Civil Service Commission for successful candidate whilst remaining under age 31. Inclusive annual remuneration for a 45½-hour week (men) £475–£877, women somewhat lower. Forms from M.L.N.S. Technical and Scientific Register (K), Almack House, 26 King Street, London, S.W.1.

EXPERIENCED RESEARCH GRADUATE required for research on cobalt alloys in Ontario, Canada. Passage paid. Apply in the first instance to Deloro Stellite, Ltd., Shirley, Birmingham. Attention: Technical Manager, Confidential.

FULMER RESEARCH INSTITUTE has two vacancies for metallurgists or physicists for equilibrium studies of reactive metals and for general metallurgical and X-ray work. Candidates should have good honours degree in physics or metallurgy. Previous experience not essential, salary according to qualifications and experience in range £600–£850. Apply Fulmer Research Institute, Stoke Poges, Bucks.

METALLURGIST is required by Marconi's Wireless Telegraph Company for their new factory at Basildon, Essex. House available to rent to selected applicant who must have had some experience in a manufacturing industry. Please apply to Dept. C.P.S., Marconi House, Strand, W.C.2, quoting Ref. 1165A.

METALLURGIST or engineer required by a company of non-ferrous metal manufacturers as the nucleus of a specialist advisory service. An ordinary degree or Associateship in metallurgy or in engineering and sound experience are necessary qualifications. Salary will be paid according to experience, and is in the range of £750–£1000 per annum. Apply in writing to Personnel Dept., The Aston Chain and Hook Co., Ltd., Bromford Lane, Birmingham 24.

METALLURGIST required with first-class practical and theoretical experience to take complete control of induction 125-kVA and cyanide hardening plant. Salary commensurate with position. Aldis Bros., Ltd., Sarehole Road, Hall Green, Birmingham 28.

PHYSICAL METALLURGISTS 20–30 years of age to work on problems associated with developments in powder metallurgy and allied technology. Must be keen, observant, and meticulous report writer. Sheffield area. Apply Box No. 356, Institute of Metals, 4 Grosvenor Gardens, London, S.W.1.

PHYSICAL METALLURGISTS. Vacancies for physical metallurgists in a fundamental research laboratory. Several years' research experience since graduation required. Interest in the nature of high-temperature alloys and equilibrium-diagram techniques an advantage for one post. Apply in writing to Personnel Officer, Associated Electrical Industries, Ltd., Research Laboratory, Aldermaston Court, Aldermaston, Nr. Reading, Berks.

SENIOR METALLURGIST. As a result of increased laboratory facilities, a vacancy exists in the Midlands for a Senior Metallurgist responsible to the Chief Metallurgist. Applicants, between 30 and 35 years of age, with a First or Second Class Honours Degree and experience in casting and extrusion, are invited to send particulars of experience and salary required to Box No. 357, Institute of Metals, 4 Grosvenor Gardens, London, S.W.1.